

EXECUTIVE FUNCTION AND HEALTH BEHAVIOR

by
Sarah Godby Vail, M.A.

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Dissertation Abstract

Introduction: A growing field of public health research aims to understand the cognitive processes involved in health behavior; executive function (EF) has been the focus of recent attention (Dunn, 2010; Williams & Thayer, 2009). This dissertation is presented as three manuscripts aiming to explore the association, theoretical underpinnings, and methodological issues of EF as a salient construct for understanding health behavior.

Methods: Manuscript 1 presents data collected from the Baltimore Memory Study on 926 community-dwelling older adults in Baltimore, MD. Multiple linear regression analysis examined the association of EF and a composite health behavior measure that included dietary intake, physical activity, smoking, and alcohol consumption.

For manuscript 2, a literature review was conducted to identify empirical articles about EF and health behavior. Thirty-six articles were analyzed to examine EF measurement, theoretical approach, and findings. Two major theoretical perspectives were identified: 1) intention-based, rational actor models and 2) dual process models. Seventeen articles using these approaches were analyzed further in Manuscript 3.

Findings: Analysis in Manuscript 1 detected a small but positive association between EF score and overall health behavior after controlling for several sociodemographic factors. Further analysis suggests that EF is also associated with physical activity, alcohol consumption, and smoking but not dietary intake.

Literature review results in Manuscript 2 suggest a pattern of association between the EF/health behavior relationship and point to varied roles for EF on health behavior, many ways of measuring EF, and many theoretical explanations for this relationship.

Analysis results in Manuscript 3 suggest two explanations for EF's role in health behavior: as a moderator of the intention/behavior relationship and as a moderator of the relationship between associative processes and health behavior.

Conclusions: These findings add to building evidence that EF may play a role in the health behaviors of older adults and suggest that EF may extend the ability to maintain health into older age. This area of study is nascent; as the field grows, researchers are encouraged to pay attention to the theoretical explanation for the EF/health behavior relationship, as well as the measurement and temporal relationship of EF and health behavior.

Advisor: Ann Carroll Klassen, Ph.D

Readers: Michelle Carlson, Ph.D
Lawrence Wissow, MD, MPH
Jennifer Schrack, Ph.D

Alternate: Margaret Ensminger, Ph.D

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CHAPTER 1: INTRODUCTION

Background

Chronic disease currently accounts for seven of 10 deaths in the United States (Kung, Hoyert, Xu, & Murphy, 2008), creating public health priorities that aim to prevent the avoidable mortality of chronic disease by addressing the behaviors that can avert and treat these diseases. Unlike the infectious disease prevention of past public health eras that required a one-time behavior for treatment and prevention (e.g., vaccination), the behaviors necessary to prevent and treat chronic disease are acknowledged to be more difficult to change and maintain. Public health models have evolved to better conceptualize this complexity, moving from individual models to more ecological models that acknowledge the numerous influences on health behavior, including physical environment, social norms, and cultural influences, as well as a convergence of biological and cognitive factors (Glass & McAtee, 2006; Hall & Fong, 2007) as individuals navigate the physical and social environments of their daily lives.

A growing field of public health research aims to understand and harness these cognitive processes involved in health behavior. Key among the study of cognitive factors associated with health behavior is executive function (EF), which has become a focus of recent attention in public health and health psychology research (Dunn, 2010; Williams & Thayer, 2009). Executive function is a neuropsychological construct representing the “higher order” cognitive abilities associated with making decisions, forming goals, planning, organizing, devising strategies for attaining goals, and when necessary, revising those plans (Coolidge & Wynn, 2001) and is conceptualized as the abilities that individuals take with them into any situation (Allan, Johnston, & Campbell, 2011). Executive function has been linked with significant variance in all-cause mortality (Duff, Mold, & Gidron, 2009; Hall, Dubin, Crossley, Holmqvist, & D’Arcy,

2009) and shown to predict survival from chronic illness (cardiovascular conditions, diabetes, and cancer) among initially healthy older adults (Hall, Crossley, & D'Arcy, 2010). It has also been shown to predict important health behaviors, including treatment adherence (Insel, Morrow, Brewer, & Figueredo, 2006), substance use (Hall, Elias, & Crossley, 2006), stress regulation (Williams, Suchy, & Rau, 2009), rehabilitation behaviors (Solberg Nes, Roach, & Segerstrom, 2009), physical activity (Hall, Elias, et al., 2008), and eating behaviors (Hall, Fong, Epp, & Elias, 2008).

Among the suggested explanations for these findings is that the self-regulatory capacities associated with EF – such as planning, monitoring behavior, making decisions -- enable the “consistent enactment of healthy behavioral patterns over the lifespan” (Hall et al., 2010, p. 124) that lead to better health. Additionally, it is suggested that inhibitory aspects of EF help individuals resist the growing number of tempting situations in the modern environment that conflict with healthy behavior (Hall et al. 2008). Hall and Fong (2007) explain that while healthy behaviors are associated with many long-term benefits and minimal long-term costs, they can also have many short-term costs and relatively fewer short-term benefits. Navigating this “now vs. later” dilemma requires individuals to effortfully regulate their behavior to meet long-term goals and to maintain it over a lifetime.

The goal of this dissertation is to contribute to the growing literature on this topic by exploring the association, theoretical underpinnings, and methodological issues of EF as a salient construct for better understanding health behavior and for informing public health interventions that can improve the health behaviors and contribute to a population-level reduction of chronic disease. The first analysis in this dissertation investigates the

association of EF and four health behaviors (and an overall measure of health behavior) among a population of older adults to test the hypothesis that EF would be associated with overall health behavior score. The analysis also looks at EF as a moderator of the relationship between age and health behavior, which has implications for interventions targeting the goal of healthy aging.

Executive function has been implicated in the addiction literature for some time, but its growth in public health research has been more recent. The increase in published articles on this topic is likely attributable to Hall, Elias, and Crossley's 2006 paper that examined the predictive power of EF on health protective and health risk behaviors. The following year, Hall and Fong (2007) published an article on Temporal Self-Regulation Theory, an explanatory model of health behavior that includes "brain-based control resources" and cited EF as the biological basis for self-regulatory abilities that are implicated in health behavior. In the years since, a growing number of articles studying the role of EF in health behavior has been published, primarily in health psychology, but no known review of this literature has been conducted. The second analysis in this dissertation fills this gap by examining the extant literature on EF and health behavior, including a summary of findings by health behavior and an investigation of salient measurement issues for studying EF and health behavior.

Public health researchers and policymakers are also beginning to draw on this research about the cognitive processes related to health behavior to inform interventions. The Obama administration recently developed a special team modeled after the United Kingdom government's Behavioral Insights Team, which applies research from behavioral science to policy delivery to encourage and support citizens to make good

choices for themselves (Behavioural Insights Team, 2014; Subramanian, 2013). The application of this research is often in the form of “nudges,” defined as making small changes to an environment to encourage good behavior without compelling it. Examples include making higher-fat items on a salad bar more difficult to reach (Rozin et al., 2011) and making elevator move at slower speeds so as to make taking the stairs more appealing (Faskunger, Poortvliet, Nylund, & Rossen, 2003). Underlying many of these interventions is an understanding of how individuals absorb, process, and react to information from their environments. While these interventions may be novel and may make practical sense, it is acknowledged that more research in this area is needed, both to collect evidence on efficacy and to better understand the mechanisms at play (Marteau, Hollands, & Fletcher, 2012).

Many health behavior models have considered health behaviors as “as reasoned, conscious, and intentional acts that require a person’s volitional control or willpower in order to be effective” (Hofmann et al, 2008), though more recent theories are drawing on social and neuropsychology to better align with the psychological and neuroscientific evidence that maintains that much human behavior is automatic rather than deliberate (Marteau et al., 2012). The public health/health psychology literature has primarily focused on the role of EF and the ability to realize health intentions, investigating EF as a modifier of the effect of intention on health behavior in individuals with high and low health behavior intentions.

Specific Aims

The aims guiding this dissertation research involve better understanding the relationship between EF and health behavior. Specific aims follow.

Aim 1: Executive Function and Health Behavior

- To determine whether the association between EF score is associated with older adults practicing healthy behavior, after controlling for other factors.
- To determine whether the association between EF and behavior varies by specific health behavior (i.e., diet, physical activity, smoking, alcohol consumption).
- To investigate whether EF moderates the relationship between age and health behavior.

Aim 2: Extant Literature of Executive Function and Health Behavior

- To conduct a review of the literature of EF and health behavior, considering measurement of EF, the type and nature of health behavior measured, and theoretical explanations of the relationship.

Aim 3: Executive Function and Health Behavior Theory

- To consider ways that EF can be represented in health behavior models to more fully conceptualize health behavior.

Significance

Results from this dissertation contribute to public health research in several ways. First, this study adds more data to the evidence for the association of EF with the health behaviors that contribute to preventable death, especially in the older adults, a population in which EF abilities are known to decline. Findings from this analysis could have important contributions to the knowledge about healthy aging. Additionally, this dissertation contains the only known review of the literature on EF and health behavior. The collective review of these studies offer observations and guidance about the

methodological issues unique to this area of research that can serve the field well as it develops. The findings from the intentional vs. non-intentional health behavior analysis contribute to the theoretical conceptualization of health behavior that can inform public health interventions.

Overview of Key Concepts

The remainder of this chapter provides an overview of topics that are salient for this research. The first section reviews health behavior in the older adult population. The next section is an introduction to the EF construct and its measurement. The final section summarizes recent health behavior theories with a cognitive component.

Health Behavior in Older Adults: Prevalence and Correlates

The United States is at the beginning of a demographic shift in which the proportion of older adults will swell by 138% from 2000 to 2050. By 2050, one in five Americans will be age 65 or older. Even more dramatically, the proportion of the “oldest old” – those over the age of 85 – will grow 377% by 2050. Healthcare researchers predict that this shift will have powerful economic, societal, social support and healthcare system implications (Goulding, Rogers, & Smith, 2003).

Much of this shift is attributed to the extended life expectancy brought about by advances in healthcare and breakthroughs in medicine. As a result, infectious disease as a major cause of mortality has been replaced by chronic disease such as heart disease, cancer, and stroke. Chronic disease currently accounts for seven of top ten causes of death in the United States (Centers for Disease Control and Prevention, 2013). The prevalence of chronic disease and multiple chronic diseases increases with age, and the proportion of middle-aged and older adults with multiple chronic conditions has

increased over the past 10 years (Freid, Bernstein, & Bush, 2012), but health experts assert that this fate is not inevitable. Evidence suggests that poor health does not have to be part of growing older (Centers for Disease Control and Prevention, 2010).

In this vein, member nations of the World Health Organization recently set a new goal of reducing premature mortality from chronic disease by 25% by the year 2025 and adopted a new set of chronic disease policies to promote healthy aging and well-being. Part of these goals for older adults target the reduction of tobacco use, harmful use of alcohol, unhealthy diet, and physical inactivity (World Health Organization, 2012), four “modifiable lifestyle factors” that have been shown to account for nearly 40% of annual deaths in the United States (Mokdad, Marks, Stroup, & Gerberding, 2004).

Healthy behavior can prevent much disability, delay mortality, and improve the quality of life in older age (Aldana, 2003), and behavior change even in later life is associated with health benefits (Hermanson, et al., 1988). Health damaging behaviors such as physical inactivity, poor diet, smoking and heavy alcohol consumption have been associated with an increased risk of disability and death in older people (Chakravarty et al., 2012; Féart et al., 2011; LaCroix, Guralnik, Berkman, Wallace, & Satterfield, 1993). Protective behaviors such as fruit and vegetable consumption, physical activity, moderate alcohol consumption, and not smoking have also been attributed to increased cognitive (Sabia et al., 2009) and physical functioning (Maraldi et al., 2009; Tsubota-Utsugi et al., 2011).

The sections below summarize the prevalence and correlates of these health behaviors in the older adult population.

Physical Activity

The Department of Health and Human Services recommends that older adults perform at least 150 minutes of moderate intensity aerobic activity and muscle strengthening activities at least twice per week (U.S. Department of Health and Human Services, 2008). Census data show that older segments of the population exercise less than do younger ones; in 2011, 34.9% of adults over 65 years of age met these guidelines, the lowest proportion of any adult age group, with 14.6% of the oldest adults (those 85 years or older) meeting activity guidelines (U.S. Census Bureau, 2012).

Older women are less likely to exercise than are older men (52.4% of men and 45.4% of women); data indicate that women report no physical activity at a rate of about 4% higher than men (U.S. Census Bureau, 2012). Non-white individuals are less likely to participate in physical activity (Schoenborn, Adams, & Peregoy, 2013). Education is associated with physical activity, with those of less education being less likely to participate in physical activity (Schoenborn et al., 2013). Living in rural areas is also associated with less physical activity in older adults, especially women (Scharff, Homan, Kreuter, & Brennan, 1999). Disability is associated with physical activity levels in older adults; Rimmer, Wolf & Armour (2007) reported results from the 2003 Behavioral Risk Factor Surveillance System survey estimating that 26.2% of older adults without disability met physical activity recommendations, compared with 14.7% of those with disability.

Dietary Intake

The Healthy Eating Index (HEI) is a measure of dietary quality used by the United States Department of Agriculture (USDA) to assess conformance to federal dietary guidelines and to monitor the diet quality of the U.S. population (U.S. Department

of Agriculture, 2010). The overall score is a sum of 10 dietary components, with an overall maximum score of 100; high scores indicate dietary intakes close to the recommended levels. In 1999-2002, the mean overall score for adults over age 60 was 66.6. Seventeen percent of older adults had a diet quality rated as “good,” 14% had a “poor” diet, and 68% had a diet that “needs improvement.” (CDC, 2008). Women had higher overall HEI scores than did men. Race and ethnicity is associated with overall HEI score, with non-Hispanic whites having higher scores than African Americans (Bowman, Lino, Gerrior, & Basiotis, 1998). Individuals with higher levels of education had higher overall HEI scores than did those with less than a high school diploma. Smoking status was associated with overall HEI score, with non-smokers being closer to meeting HEI guidelines than current smokers (CDC, 2008).

Smoking

Recent results from the National Health Interview Survey (NHIS) estimate that adults over 65 represent the age group least likely to be current smokers (12.6% of adults 65 to 74 years and 5.6% of adults 75 or more years), but suggest that among daily smokers, older adults are more likely than other age groups to smoke more cigarettes when they do smoke; daily smokers between 65 and 74 smoked an average of 15.6 cigarettes per day, more than any other age group (those over 75 smoked an average of 12.9 cigarettes per day) (Schoenborn et al., 2013). Older women are less likely to smoke than older men; 7.5% of older women and 10.6% of older men smoke (Agaku, King, & Dube, 2014). Education status shows a gradient scale with smoking, with those of the highest levels of education indicating the lowest prevalence of current smoking (5.7% with a graduate degree vs. 28.7% of those with a high school diploma. Those with a GED

seem to be the exception, with 44.5% of those individuals reporting to be current smokers) (Agaku et al., 2014). White and black adults have similar prevalence of current smoking (20.8% and 20.2%, respectively), while American Indians/Alaskan Natives are slightly more likely to smoke (22.9% prevalence) and Asians are half as likely to smoke (10.2% are current smokers) (Agaku et al., 2014).

Alcohol Consumption

About half of adults from 65 to 74 (51.6%) and 38.9% of those 75 or older report to be current drinkers, lower proportions than in other age groups (Schoenborn et al., 2013). While some research suggests the benefit of moderate alcohol consumption, binge drinking accounted for an estimated average of 80,000 deaths and 2.3 million years of potential life lost each year, and an estimated \$223.5 billion in economic costs in 2006 (Bouchery, Harwood, Sacks, Simon, & Brewer, 2011). Blazer and Wu (2009) predict that at-risk drinking among older adults will increase as a result of the aging baby-boomer population.

Alcohol consumption recommendations for older adults is no more than 1 standard drink (12 ounces of beer, 4 to 5 ounces of wine or 1.5 ounces of distilled spirits) per day or 7 standard drinks per week and no more than 3 drinks on one occasion (National Institute on Alcohol Abuse and Alcoholism, n.d.). Binge drinking is defined as consuming five or more drinks (for men) or four or more drinks (for women) during one occasion. In 2011, 4.3% of adults over the age of 65 reported binge drinking within the past 30 days, the smallest proportion of all age groups, compared to 28.2% of 18 to 24-year olds. Older adults binge drank most often of all age groups, however – an average of

4.9 times per month, though they drank with the least intensity (an average of 5.6 drinks) when they did binge drink (Kanny, Liu, Brewer, Garvin, & Balluz, 2012).

In an analysis of 2010 BRFSS data, Kanny et al. (2012) reported that men were more likely than twice as likely as women to binge drink (23.2% of men, compared with 11.4% of women), and that non-Hispanic whites and Hispanics were more likely than other race/ethnicity groups to be binge drinkers (18.0% and 17.0%, respectively).

Education was also associated with frequency of binge drinking. Individuals with at least some college education had the highest binge drinking prevalence, but had the lowest binge drinking frequency and intensity (Kanny et al., 2012), compared with those with less than a high school diploma, who reported an average of 5.5 binge drinking episodes per month and 9.3 drinks during a drinking episode (Kanny et al., 2012). Similarly, household income is also associated with binge drinking. Those of the highest income (>\$75,000) had the highest binge drinking prevalence than other income groups (22.2%), though they had the lowest frequency of binge drinking (3.6 occasions per month) and the lowest intensity (6.5 drinks) than other income groups (Kanny et al., 2012).

Executive Function

Executive function is a neuropsychological construct representing the “higher order” cognitive abilities that are associated with making decisions, forming goals, planning, organizing, devising strategies for attaining goals, and when necessary, revising those plans (Coolidge & Wynn, 2001). Executive function is conceptualized as the abilities that individuals take with them into any situation and that play a general role in the implementation of intended actions (Allan et al., 2011).

Executive function is a relatively new neuropsychological construct, tracing its roots from the “central executive” described by Baddeley and Hitch (1974), along with Luria’s frontal lobe research (1973) and defined further by Lezak (1983). This term likens executive functioning to the actions of a corporate executive overseeing business operations who takes in information from other sources, makes decisions, and directs attentional and other resources to implement the necessary actions to meet company goals and priorities. Neuroimaging studies have identified that these abilities emanate from the brain’s prefrontal cortex (PFC), which has greater access to the other regions and functions of the brain than any other brain structure. The PFC receives input from all sensory modalities and the outside world to react to stimuli (Suchy, 2009). In contrast to the brain’s more automatic reactions (such as the “fight or flight” response), the role of the PFC is essentially to interrupt and “stretch out” time between a stimulus and response (Tucker, Derryberry, & Luu, 2000). This allows higher-order thinking to compare and discard many possible plans or strategies in favor of what is likely to be the most beneficial in the long run, that is, “to be reflective rather than impulsive” (Lewis & Todd, 2007, p. 410).

Research from patients with prefrontal damage has contributed substantially to the understanding and conceptualization of EF. Luria (1966) contributed to this understanding by studying the abilities of individuals with damage to the prefrontal region. These patients are often otherwise healthy with speech and motor function and relatively normal IQ levels but display a lack of flexibility and the ability to grasp, attend to, and process new information. They are unable to conduct goal-directed actions and cannot evaluate success or failure of their behaviors. Such individuals are often stimulus-

driven, eating anytime they see food and kicking when they see a ball, regardless of whether these actions are appropriate. One of the first and now classic descriptions of EF deficits is that of Phineas Gage, a railroad foreman who suffered an injury in 1835 when a tamping rod penetrated his skull and damaged his frontal lobes. He survived the accident in good health but was afterward a dramatically different man with a “childish” and irresponsible personality, making plans then quickly abandoning them, becoming irreverent and capricious. He was so unlike his former self that his loved ones said that he was “no longer Gage” (Macmillan, 1986).

Through these and other studies, EF has come to be understood as the abilities that allow individuals to shift their mindsets quickly and adapt to diverse situations while at the same time inhibiting inappropriate behaviors. They enable us to create a plan, initiate its execution, and persevere on the task at hand until its completion (Jurado & Rosselli, 2007).

EF stands in contrast to the brain’s more “automatic” processes, which are performed without intentional direction. Automatic processes are learned and develop over time in response to stimuli and circumstances. Actions, processing schemes, and routines become associated with stimuli, and eventually they become linked with each other so that a cascade of action occurs when a stimulus is encountered (Hughes, 2005). For example, seeing that one’s shoelaces have come untied will likely trigger an automatic response of bending down and retying them without considering or thoughtfully directing every intermediate step. Thus, it is important to recognize that any response that is automatic, habitual or routine is not a reflection of EF (Suchy, 2009). Hughes (2005) suggests that EF differs from automatic processes in that it 1) is the

execution of novel vs. routine action sequences, 2) involves the choice of alternative responses vs. a single action sequence (e.g., the shoe tying example above), and 3) is the execution of actions that require access to consciousness. In fact, one aspect of EF is the ability to override a habitual reaction (termed “prepotent response” in the neuropsychology literature) when necessary. Suchy (2009) explains that EF is a highly effortful and, from an energy consumption standpoint, a costly process and is generally used only when needed, such as during novel or complex situations that require more than an automatic or routine response.

Friedman and Miyake (2012) explain that individual differences in EF among a particular population are largely attributable to genetics, but these authors note that the genetic component addresses variability across individuals at one point in time only and not EF “trainability,” which has been suggested by some researchers (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008). This also does not address the state-like features of the cognitive underpinnings of self-regulatory abilities.

Though the neuropsychology field generally agrees on the importance, complexity, and general nature of EF, there is much variation in the conceptualization of it. Two main explanations exist: the “theory of unity,” which suggests a singular underlying ability that explain all components of EF (Barkley, 1997; de Frias, Dixon, & Strauss, 2006; Duncan, Emslie, Williams, Johnson, & Freer, 1996; Kimberg, D’Esposito, & Farah, 1997; Parkin & Java, 1999), and one of “non-unity,” which posits that EF can be divided into several components that are distinct parts of an overall construct (Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999; Lehto, 1996; Miyake et al., 2000; Salthouse, Atkinson, & Berish, 2003).

Miyake and Friedman (2000) suggest that EF likely has both a unitary and non-unitary component. They point to three related, but distinct constructs that have become the most widely reported EF factors: response inhibition (the ability to attend to a goal and to inhibit a habitual response in favor of a less used but more appropriate response), updating or working memory (the ability to monitor and hold and manipulate information in short-term memory), and set shifting (the ability to switch between tasks). Despite identifying diversity in these distinct parts, these authors also suggest commonality among all components that is most likely lies in a basic inhibitory and working memory mechanism (Miyake & Friedman, 2012).

Measuring Executive Function

Having such variation in definition makes the measurement of the EF construct very difficult, and many approaches exist. There is no single global test for EF, so neuropsychologists rely on tests that are known to tap frontal lobe functions, with most measurement instruments being task-based and primarily concerned with detecting dysfunction in clinical populations (Jurado & Rosselli, 2007). Suchy (2009) differentiates between two types of EF assessments: clinical tests, such as the Wisconsin Card Sorting test, the Trail Making test (Part B), and measures of verbal and figural fluency; and experimental tasks, such as the Stroop task, the Go/No-Go task, and N-back task.

Researchers point out several problems with the current techniques to measure EF. First, EF is an ability called upon in situations of novelty, whereas EF tasks are often very structured, with the test administrator essentially becoming the central executive by providing direction instead of challenging the individual's ability to react to a novel stimulus (Stuss & Alexander, 2000). Additionally, the networked nature of the PFC

means that EF tasks are essentially measuring many areas of the brain (Burgess, 1997). To truly isolate EF, one would need to be able to identify and remove all the other abilities used in the task. Finally, researchers admit that EF tests lack ecological validity; it is rather unclear how well test performance may manifest in everyday life (Chaytor, Schmitter-Edgecombe, & Burr, 2006).

Despite the dispute on the exact conceptualization and measurement of EF, neuropsychology seems to agree about the important role that EF plays in daily life, suggesting that it is “the heart of all socially useful, personally enhancing, constructive and creative abilities” (Lezak, 1982). It is particularly associated with several psychological constructs related to health behavior and behavior change: self-regulation (Miyake & Friedman, 2012), emotional regulation, delayed gratification, attentional control, and self-monitoring (Williams & Thayer, 2009). Suchy (2009) suggests that EF is what frees humans from “over-practiced, over-learned, and prepotent responses” as well as “innate, hard-wired drives and reflexes” by allowing them to consider options, apply lessons learned from past situations, and make decisions toward long-term goals. Given that these constructs are needed to maintain health behavior, it is not surprising that Williams and Thayer (2009) prioritize gaining more understanding about EF in the maintenance of health behavior and avoidance of risk behavior as an important research goal.

Executive Function and Older Adults

Executive function abilities have been widely reported to decrease with increasing age (Brennan, Welsh, & Fisher, 1997; Donald R. Royall, Palmer, Chiodo, & Polk, 2004), with longitudinal studies demonstrating deterioration at an exponential rate (Royall et al.,

2004). Decline in EF is associated with many aspects of life as an older adult given EF's role in the ability to successfully navigate new and complex environments and to marshal attentional resources for responses to environments (Royall et al., 2002).

Executive function is often associated with decline in mobility and balance (Coppin et al., 2006), physical function (Carlson et al., 1999), as well as instrumental activities of daily living (such as housework, preparation of meals, and dressing) (Carlson et al., 1999), and adherence to medical regimens (Insel et al., 2006). Financial, medical (Royall, Cordes, & Polk, 1997), and other functional decision making is also impaired, which some researchers attribute to a decreased awareness of a task's inherent risk, precluding the individual's perception of the need to modify behavior in response to that risk (Coppin et al., 2006).

Related Health Behavior Theories

Early conceptualizations of health behavior change focused on individual psychological factors and proximal interpersonal influences. Theories such as the Social Cognitive Theory (Bandura, 1986), the Theory of Reasoned Action (Fishbein & Ajzen, 1975), and the Theory of Planned Behavior (Ajzen, 1991), the Health Belief Model (Janz & Becker, 1984) and the Stages of Change model (Prochaska, DiClemente, & Norcross, 1992) have a common feature in conceptualizing behavior as being "reasoned, conscious, and intentional acts that require a person's volitional control or willpower in order to be effective" (Hofmann, Friese, & Wiers, 2008). Recent research in social neuroscience and behavioral economics are adding constructs that are being incorporated to the models to capture the complexity of health behavior. The sections that follow describe several of these constructs and theories.

Self-Regulation Theory

Self-regulation (also called self-control) is a construct widely discussed within the social and health psychology literature, especially in the last 20 years. Self-regulation is rooted in Bandura's Social Cognitive Theory (1977, 1986) which describes behavior as being determined by the confluence of personal, behavioral, and environmental influences. The theory posits that individuals engage in behavior because of the outcomes they hope to achieve, and self-regulation is considered to be the process by which an attempt is made to reach these goals (Bandura, 1991). Bandura acknowledged that this process demands a higher level of functioning and involves standard setting, self-evaluation and self-reinforcement, as well as a learned response (Clark & Zimmerman, 1990).

Simply put, and as its name suggests, self-regulation describes the ability to regulate oneself. Though definitions vary, it is generally acknowledged as the mental energy required for the self to alter its own responses or inner states, such as thoughts, emotions, and behaviors, replacing a more pleasurable or automatic response with a less common one that is associated with long-term best interests (Baumeister & Vohs, 2004). Several components of this definition highlight important features of the self-regulation construct that are critical to understanding it.

High-order thinking such as self-regulation is costly in terms of energy requirements; research findings by Gailliot et al. (2007) reported that an act of self-regulation requires more blood glucose than do other mental acts. Some researchers have suggested that this feature of self-regulation is an important one in understanding what they call "self-regulation failure," that is, when people do things that are not in their long-term best interest or according to their goals. Based on their research, Baumeister,

Heatherton, and Tice (1994) introduced the self-regulatory strength model, which proposes that the ability to self-regulate is an effortful act and requires a resource that is limited. Self-regulatory strength refers to “the internal resources available to inhibit, override, or alter responses that may arise as a result of physiological processes, habit, learning, or the press of the situation” (Schmeichel & Baumeister, 2004, p. 86). This strength is considered as a resource meant to be expended but limited in quantity. When this resource is depleted, the aforementioned self-regulation failures are more likely to occur. This resource can be depleted by emotion regulation, impulse control, making active choices, switching tasks, and solving complex problems (Schmeichel & Baumeister, 2004). This model suggests that the self-regulation resource works like a muscular strength, which is depleted as muscles are used and which is restored only after rest. These authors suggest that similarly to muscle strength, people seek to conserve self-regulation once it begins to be depleted; they also suggest that self-regulation can be gradually increased by exercise (Schmeichel & Baumeister, 2004).

Temporal Self-Regulation Theory

In 2007, Hall and Fong introduced Temporal Self-regulation Theory (TST), asserting that despite widespread knowledge about health behaviors, prevalence of the key modifiable lifestyle factors is still high for two chief reasons: 1) the “palpable seduction” of unhealthy behavior and 2) the constraining forces of environments, biological predispositions, and natural cognitive proclivities.

Key to this theoretical consideration is the notion that nearly all health behaviors can be described in terms of many short-term costs and relatively fewer short-term benefits. On the other hand, they are also associated with many long-term benefits and

minimal long-term costs. Hall and Fong suggest that absent temporal differences, long-term benefits far outweigh short-term benefits. These temporal differences, which underscore the “now vs. later” dilemma, require individuals to effortfully regulate their behavior to meet long-term goals. The theory suggests that the capacity to do so depends upon the convergence of biological, cognitive, and social factors. Similar to previous health behavior theories, TST suggests that intention does drive behavior, but that this relationship is moderated by self-regulatory capacity and behavioral prepotency, as well as the environmental contingencies. The theory includes feedback loops in which positive behavioral outcomes fuel intentions, behavioral prepotency and self-regulatory capacity.

Furthermore, the theory differentiates between health behaviors performed in favorable and unfavorable environments. It hypothesizes that the relative predictability of behavior from these constructs depends on the structure of the social and physical environment. The theory suggests that in unfavorable contexts, healthy behavior requires more motivation and self-regulatory resources, while in supportive environments, healthy behavior is more a function of behavioral intention and past behavior.

Dual Process Theory

Dual process theories trace back to 19th century American psychologist William James, who described two cognitive processes: associative and reasoning. One dual process theory increasing in application to health behavior, especially addictive behaviors, is Strack and Deutsch’s (2004) Reflective-Impulsive Model (RIM). This theory distinguishes two information-processing modes: an impulsive mode that is “fast” and outside the awareness and draws upon the store of associations that the person has

acquired over many experiences; and the reflective mode, which is “slow,” based on logic rather than associations, and is accessed intentionally.

Dual process models has been applied in the alcohol addiction literature, in which addictive behaviors are conceptualized as the joint outcome of the “impulsive” process, which is usually considered to be appetitive, and the reflective process, which is typically considered as an EF. The models state that behavior is generally the outcome of the relative strengths of these two systems – that impulsive processes can be controlled by EF, but that these require motivation and executive abilities, which are not always available (Wiers et al., 2007).

Wiers et al. (2009) suggested that it is the coupling of an EF deficit with the relevant associative process that is associated with poorer behavior, explaining that impulsive behavior (such as aggression, unsafe sex, alcohol or drug use) is not merely a matter of low EF abilities, but also an associative process that leads to a particular behavior. Conversely, Sharbanee et al. (2014) suggested that while associative processes can account for motivation to consume alcohol, their research suggested that it alone is insufficient for dysregulated drinking, hypothesizing that such drinking may be the result of an imbalance of associative processes and interference suppression.

Nudge Theory

The Obama administration recently developed a special team modeled after the United Kingdom’s government’s Behavioral Insights Team, which applies research from behavioral science to policy delivery to encourage and support citizens to make good choices for themselves (Behavioural Insights Team, 2014; Subramanian, 2013). The application of this research is often in the form of ‘nudges,’ defined as making small

changes to an environment to encourage good behavior without compelling it. Examples include making higher-fat items on a salad bar more difficult to reach (Rozin et al., 2011) and making elevator move at slower speeds so as to make taking the stairs more appealing (Faskunger et al., 2003).

Nudge interventions are defined as “any aspect of the choice architecture that alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives” (Marteau et al., 2012). These interventions rely on “choice architecture,” a term coined by Thaler and Sunstein (2008), to describe the way that choices are presented to consumers and relies on an understanding of how individuals absorb, process, and react to information from their environments. Nudge interventions shape choice designs that steer individuals toward a healthy decision without making it mandatory. Many nudges call on the cognitive automatic processes, and nudge experts suggest that more research is needed in this area to understand the mechanisms behind such interventions (Marteau et al., 2012).

Marteau et al. (2012) suggests that while nudge interventions acknowledge automatic processes in ways that other theories and interventions do not, there is a need for both primary research and synthesis of existing evidence to examine the effectiveness and acceptability of nudging interventions, including which nudge interventions work, and in which populations, circumstances, and time periods they work.

Dissertation Overview

This dissertation comprises six chapters.

Chapter 1 is an introduction to the dissertation, providing background information, an overview of the EF construct and an introduction and theories guiding the

research. It also presents a description of the research aims and the significance of this work in the field of behavioral public health.

Chapter 2 is a description of the research methods used in this study.

Chapter 3 presents results from an investigation of the association of EF with four health behaviors as well as a composite measure of health behavior in older adults.

Chapter 4 describes results of a literature review of the extant literature on EF and health behavior, including a summary of findings by health behavior and an investigation of salient measurement issues for studying EF and health behavior. The manuscript also makes recommendations for future research.

Chapter 5 proposes that existing health behavior models would benefit from incorporating automatic process constructs from dual process theories and suggests that our understanding of the role of EF in health behavior can be broadened through an appreciation of dual process models. The chapter includes an overview of intention-based health behavior theory and dual process models and a comparison of articles from the EF/health behavior literature using intention-based and dual process perspectives. The chapter concludes with a discussion of implications for health behavior interventions.

Chapter 6 summarizes the findings of each of the analyses. It addresses overall study strengths and weaknesses and synthesizes all findings to offer a higher-level perspective on EF and health behavior. Finally, the chapter fits these findings into the current state of behavioral public health research and intervention and suggests areas for future research and intervention.

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CHAPTER 2: RESEARCH METHODS AND PROCEDURES

Introduction

This chapter describes the methods used in this dissertation research about the relationship between executive function (EF) and health behavior. Methods used for the regression analysis in chapter 3 are described first. Those methods include the project's study setting, data collection approach, study population, data sources, and study variables, as well as the statistical analysis and model fit approaches. Next, methods used for the literature review research in chapters 4 and 5 are described.

Study Setting

Baltimore City is located in the north central area of the state of Maryland. It is the state's largest city, with 651,154 residents in 2000 (U.S. Census Bureau, 2002b), the population having declined since the manufacturing boom before the 1950s.

Demographically, Baltimore had a distinctly higher percentage of African-Americans (65.2%) than the state of Maryland (28.8%) and the United States (12.9%) in 2000 (U.S. Census Bureau, 2002b). It had a lower percentage of owner-occupied housing than the state and nation (50.3%, compared with 67.7% and 66.2%, respectively), as well as a lower percentage of individuals with more than a high school degree and lower per-capita income. Baltimore had lower per-capita income than did Maryland and the United States, as well as a higher percentage of individuals over 65 under the poverty line, and the percentage of individuals receiving public assistance (U.S. Census Bureau, 2002a, 2002c). Table 1 summarizes key demographic attributes of Baltimore, the state of Maryland, and the United States.

Baltimore City, which has been nicknamed a "city of neighborhoods," comprises more than 270 neighborhoods with boundaries established by the Baltimore City

Department of Planning in collaboration with the Johns Hopkins Center for Metropolitan Planning and Research. These neighborhoods, first defined in the 1970s and revised after the 1990 and 2000 censuses by the city planning department and area residents, are typically geographic areas with community-recognized boundaries “consistent with common community identities” (Baltimore Neighborhood Indicators Alliance, 2010).

Subject Recruitment and Data Collection

Data for this analysis come from the Baltimore Memory Study (BMS), a multilevel cohort study of risk factors for cognitive decline in older adults in Baltimore City. The study was funded by the National Institutes of Health’s (NIH) Initiative to Eliminate Racial and Ethnic Disparities in Health (2 R01 AG19604 06-09 and 2 R01 AG10785 09-11); Dr. Brian Schwartz, PI). BMS is a longitudinal study with five specific data collection visits between 2001 and 2011. Respondent data from visit 1 (2001-2002) and visit 2 (2002-2003) were used in analysis for this study.

To recruit for this study, 81 contiguous neighborhoods were selected from Baltimore City’s 270 neighborhoods, to ensure wide variability on characteristics of interest, including availability of services, socioeconomic deprivation, and racial composition, within and across race/ethnic groups (Schwartz et al., 2004). Using a sampling frame based on the Baltimore Department of Assessments and Taxation data, all residential addresses in the study area were identified and linked to telephone numbers. Six random samples were drawn from this sampling frame, and households were called up to 10 times to determine eligibility and recruitment. Eligibility was determined on 2,351 subjects (aged 50 to 70 years, living at selected households, having lived in Baltimore City for at least five years), and of these subjects, 60.8% (n=1403)

were scheduled for an enrollment visit. Of the 1403 scheduled for an appointment, 1,140 (81.3%) were enrolled and subsequently tested between May 2001 and September 2002. This study was approved by the Committee for Human Research of the Johns Hopkins Bloomberg School of Public Health. All participants provided written, informed consent before testing and were paid \$50 for their participation in each visit.

Study Population

Of the 1,143 participants who enrolled and participated in visit 1 between May 2001 and September 2002, a total of 1,033 participants (91% of the initial study population) completed a second visit between October 2002 and December 2003. Average length between visits was 15.6 months.

This analysis included only these individuals who participated in both visit 1 and visit 2 and who lived in the same neighborhood during both visits (N=976). Four participants were removed from analysis who demonstrated significant cognitive decline from visit 1 to visit 2 (scoring 1.5 standard deviations or more from the population mean of both the Trail Making test and the Stroop test, based on a similar protocol used by the study administrators). Seventeen participants were removed from analysis because they had biologically implausible values for Block Food Frequency Questionnaire (9 reported daily calories greater than 5000 and 8 who reported fewer than 500 daily calories). One participant was removed for indicating a biologically implausible number of average drinks per day. Because this study is most interested in the association of EF and health behavior in a high-functioning population, participants who scored two standard deviations or lower than the population mean EF score were removed from this analysis (n=15). Because physical functioning is directly linked to ability to maintain healthy

behavior, participants who scored a one or greater on the Katz Activities of Daily Living Index (indicating the inability or need for help to perform at least one activity of daily living (e.g., bathing, dressing, eating) were removed from analysis; 13 individuals were removed for this reason. After these exclusions, 926 participants remained in the final analysis. Figure 1 displays the breakdown of the final analysis population.

Participants in the final sample were compared to those who began the study at visit 1. Table 2 presents demographic characteristics of the initial population and the final population. Participants in the final population were more likely than those in the original population to be younger ($p=0.004$), white ($p=0.0002$), to be more highly educated ($p=0.0002$), to work full or part time ($p=0.0002$), and to have greater household wealth ($p=0.053$). There were no statistical differences in marital status or percent female.

Data Sources

Data for this study were taken from data collected during these two visits. Visit 1 included a 90-minute neurobehavioral battery; blood pressure, height, weight, and spot urine samples. Next, a structured interview was conducted, followed by venipuncture and a satisfaction survey about the visit. Data were collected by trained research assistants at the Baltimore Memory Study clinic in north central Baltimore city. During visit 2, neurobehavioral testing and structured interviews were conducted, as well as the collection of salivary cortisol samples and blood pressure.

While the neurobehavioral battery remained identical from visit 1 to visit 2, the structured interviews were focused on different topics. Health behavior data were collected over the span of both visits. Specifically, smoking and alcohol consumption data were collected during visit 1, while physical activity and dietary intake data were

collected during visit 2. Table 3 displays which data were collected in each respective visit.

Study Variables

Dependent Variables

Dietary Intake

Before reporting to visit 2, participants were asked to complete the Block 98.2 Food Frequency Questionnaire (Block, Hartman, & Naughton, 1990), an instrument of dietary intake in which participants respond to a list of foods regarding how often they ate each food within the last year as well as the portion sizes they consumed. This instrument has been validated for a variety of populations (Boucher et al., 2006; Johnson, Herring, Ibrahim, & Siega-Riz, 2007) and has been reported to be highly reliable (Hartman et al., 1996; Leighton, Neugut, & Block, 1988).

Participant data from the questionnaire were sent to NutritionQuest for scoring, and a resulting data file of nutrient and micronutrient values was delivered to BMS researchers. To provide an overall indication of dietary intake, an eating index was created based on the 1995 Health Eating Index (HEI), a measure of dietary quality used by the United States Department of Agriculture (USDA) to assess conformance to federal dietary guidelines and to monitor the diet quality of the U.S. population (U. S. Department of Agriculture, 2010). The index calculation has since been revised (in 2006 and 2012) to reflect changes to the Dietary Guidelines for Americans, but this research used the 1995 HEI score to correspond to the published dietary guidelines during that time period.

The 1995 HEI score is the sum of 10 dietary components, five regarding adherence to the USDA food pyramid and five assessing intake of total fat, saturated fat, cholesterol, sodium, and dietary variety. For each component, a score from 0 to 10 is assigned, with a higher score indicating a healthier diet. Component scores were totaled to reach an overall healthy eating score. The USDA classifies scores greater than 80 points as “good.” Scores between 51 and 80 are considered to “need improvement,” and scores below 51 are classified as “poor” (Basiotis, Carlson, Gerrior, Juan, & Lino, 2002).

Calculation of this dietary index followed the method of the HEI, with the exception of the dietary variety construct, which measures the degree to which a person’s diet varies. The HEI variety score is typically calculated by summing the number of different foods (those that contribute at least one-half of a serving in a food group) (Basiotis et al., 2002) consumed in one day. These data were not available, however, so a measure was created that summed the number of different solid foods consumed in one day. Table 4 displays the scoring criteria for the dietary intake index.

Physical Activity

Physical activity was assessed during visit 2 using the Yale Activity Survey for Older Adults (YPAS) (Dipietro, Caspersen, Ostfeld, & Nadel, 1993), an instrument used widely with the older adult population. This instrument has been validated and is reported to have a high degree of internal consistency (Young, Jee, & Appel, 2001). The instrument comprises two sections. The first section asks about time spent (in hours per week) in work, exercise, and recreational activities within the past month. The second section assesses time spent in vigorous activity, leisurely walking, and general movement (in hours per week).

From the second section, index scores are calculated as the product of the frequency of the respective activity (e.g., once per week), the duration of activity (e.g., 20 minutes), and an activity intensity score ranging from 1 to 5 (Dipietro et al., 1993). A Total Activity Index is calculated as the sum of the vigorous activity index score, leisurely walking index score, moving index score, standing index score, and sitting index score (Dipietro et al., 1993) and is described as an individual's total physical activity in a week with consideration to intensity. Individual index scores were calculated as the product of the frequency of the respective activity (e.g., once per week), the duration of activity (e.g., 20 minutes), and an activity intensity score ranging from 1 to 5 (Dipietro et al., 1993) for each of five categories: vigorous activity, leisurely walking, and general movement, standing, and sitting.

Several summary indices were calculated from the survey: total time, total energy expenditure, and total activity summary. Total time is the sum of time spent in all survey activities (housework, yard work, care taking, exercise, and recreation activities), expressed in hours per week. Total Activity Index is the sum of the vigorous activity index score, leisurely walking index score, moving index score, standing index score, and sitting index score. Exercise and recreation time is the number of hours spent per week in exercise or recreational activities.

Smoking

Smoking was assessed during visit 1. During the structured interview, participants were asked whether they had smoked 100 cigarettes in their lifetime, whether they currently smoke, and the average number of cigarettes they smoke per day. The average number of cigarettes smoked per day was used in analysis.

Alcohol Consumption

Alcohol consumption was measured during the structured interview of visit 1. Participants were asked whether they had consumed at least one drink in the past month, the average number of drinks per week or month that they consume, the number of drinks they consume on days that they drink, and the number of days in the past month that they consumed four or more (for women) or six or more (for men) drinks. This analysis used the average number of drinks consumed on the days when the participant drank.

Overall Health Behavior

To create a measure of overall health behavior, a composite was calculated from the measures of the four health behavior component scores (dietary intake, physical activity, smoking, and alcohol consumption). First, the scores of smoking and alcohol consumption measures were reversed so that higher scores from all component scales indicated healthier behavior. Next, each behavior score was transformed to a 25-point scale (with 25 representing healthier behavior). Behavior scores were then summed for a composite score ranging from 0 to 100, with 100 being the healthiest possible score.

Independent Variables

Executive Function

Executive function was measured using three validated neurobehavioral instruments that were administered at visit 2.

The Purdue Pegboard test (model 32020; Lafayette Instrument Corporation, Lafayette, IN; LIC 1999) is generally a measure of eye-hand coordination and manual dexterity. In this test, participants sit in front of a pegboard and a cup of pins, and are given instructions about placing the pins into the pegboard in a particular order using their dominant hand, then their non-dominant hand, then both hands together. In an

assembly task, participants are given several types of materials (pins, washers, and collars) and are given instructions to assemble an arrangement of these materials in a specific order. A score is calculated by tallying the number of correctly placed pins or assemblies. A measure of EF is calculated by subtracting the test score while using both hands from the assemblies score; this removes the aspect of the task related to manual dexterity, thereby isolating the aspect of the task that taps cognitive processing speed and attentional control (Strauss, Sherman, & Spreen, 2006).

Trail Making Test is a connect-the-dots exercise; in Test A, participants are given a piece of paper with 25 numbers and are asked to draw a line from one target to the next in numerical order. In Test B, both numbers and letters are used as targets; participants are asked to connect the targets alternating between numbers and letters (i.e., 1, A, 2, B, 3, C, etc.) Time taken to complete the test is the performance metric. To measure EF, the score from Test A is subtracted from the Test B score. By removing the aspect of test performance that is accounted for by motor speed, this score isolates an aspect of EF known as set-shifting, the ability to go back and forth between tasks or mental sets (Miyake, Emerson, & Friedman, 2000). The test is described as measuring attention, processing speed, and mental flexibility (Strauss et al., 2006). Adequate test-retest reliability has been demonstrated in neurologically stable adults aged 15 to 83, and evidence suggests that the test correlates well with other tests of attentional abilities (Strauss et al., 2006).

The Stroop Test measures an individual's ability to attend to a goal and to inhibit a habitual response in favor of a less used response. It is one of the oldest and most widely used measures for assessing attention and response inhibition. The test generally

comprises three parts, each of which requires a participant to read a list of colors. The last section assesses the examinee's ability to view a list of colors, with each word printed in a colored ink that is different than the word it represents. For example, the word red might be printed in green ink. Examinees are asked to identify the color of the ink rather than reading the word aloud. The time and accuracy in which this is accomplished is compared with the individual's scores from previous sections in which the individual reads words printed in ink that was black or that matched the color word (Strauss et al., 2006).

An EF score was calculated separately for visit 1 and visit 2 by transforming each test score to a z-score and calculating a mean score from all three scores. Additionally, an average EF score was calculated by averaging the visit 1 and visit 2 scores.

Control Variables and Covariates

Gender was self-reported during the visit 1 interview. Birthdates were captured during the visit 1 interview, and dates of each visit were recorded for each respondent, enabling the calculation of age at each visit for each respondent. Marital status was captured as a self-report question at visit 1 and a dichotomized measure was created of those who were married vs. those who were not married. Education was created using the self-report of highest educational attainment as reported during the visit 1 interview and described in the number of years of education. Body mass index was calculated using measurements taken during visit 1 by dividing weight in pounds by the square of height in inches and multiplying by 703. Quality of life was measured during the visit 1 interview. Participants were asked to rate their overall present health using the following response choices: excellent, very good, good, fair, or poor.

Household wealth was used as proxy for socioeconomic status and was measured through a series of questions during the structured interview at visit 1 and calculated as the sum of household income and household assets. Details about the methodology for construction of this variable have been published elsewhere (Schwartz et al., 2004).

Regression Analysis

Regression analysis was conducted in SAS version 9.2 and 9.3 (SAS Institute, Cary, NC) to address Research Aim 1:

- To determine whether the association between EF score is associated with older adults practicing healthy behavior, after controlling for other factors.
- To determine whether the association between EF and behavior varies by specific health behavior (i.e., diet, physical activity, smoking, alcohol consumption).
- To investigate whether EF moderates the relationship between age and health behavior.

Analysis began by examining univariate distributions of the outcome and major variables of interest. Next, a series of bivariate analyses examined the relationship between the outcome variables (health behavior scores) and the main predictor (EF), as well as between the outcome variable and a variety of sociodemographic variables. Variables with a p-value less than 0.25 were retained for multiple linear regression modeling.

A final model was built by beginning with a base model of the main predictor of interest (EF score) and control variables (age, gender, race). Variables were added to the model if they were independently associated with health behavior outcome, if they were

theoretically relevant, or if the addition of the variable substantially changed the relationship between EF and behavior score. Variables with nonsignificant coefficients were removed from each model for the sake of parsimony, with the exception of race, which significantly affected the relationship between health behavior and EF and is also known to be associated with EF in this population (Schwartz et al., 2004).

After main effects models were created, interaction terms between EF and age were created and tested in the final model to consider EF as an effect modifier between age and health behavior. To consider any other effect modification, interaction terms were created for all combination of variables and tested in the final model. Interaction terms with a p-value of 0.07 or less were included in the final models.

All models were examined for linearity, normality, multi-collinearity, and heteroscedasticity and indicators of model fit using adjusted variable plots, distribution of residuals, and variance inflation factors. Cook's distance measures were examined to identify the existence of influencers, outliers, and high leverage observations.

Literature Review

Search Strategy and Data Sources

A literature search was conducted in PubMed, Academic Search Complete, and PsycINFO to identify empirical articles about executive functioning and health behavior. We searched for studies published between 1994 and 2014 using the following search queries: (Executive function OR executive control OR executive abilit*) AND (health behavior* OR exercise* OR diet OR physical activit* OR smok* OR cigarette* OR tobacco OR alcohol OR drink*). All search results were limited to those written in

English and published in peer-reviewed journals. We also reviewed the references of each article identified for inclusion in the review.

Criteria for Inclusion in Review

Figure 1 depicts the literature search process flow. The initial search described above resulted in 1416 articles. Criteria for inclusion in review were 1) including executive function in the title or abstract; 2) including a health behavior in the title or abstract; and 3) research conducted in human adult populations. After we removed articles that did not meet the inclusion criteria, 1039 articles remained (810 from PsycINFO/Academic Search Complete and 229 from PubMed). We then merged the searches from the two databases and identified and removed 187 duplicate articles.

The resulting list included 852 articles. Because we were interested exclusively with the effect of EF on health behavior, we reviewed article titles (and abstracts, as necessary) to exclude articles for the following reasons: 1) EF was considered to be the dependent variable (e.g., the effects of physical activity on EF), 2) the article was not empirical (e.g., a literature review), 3) the population of interest had a condition or diagnosis known to affect EF (e.g., schizophrenia), 4) the article focused on a health condition (e.g., obesity) rather than a health behavior (e.g., dietary intake) as the dependent variable, 5) the articles was not related to health (e.g., the functions of an office executive).

This review removed 789 articles, leaving 24 remaining articles. The references of the remaining articles were examined for additional articles. This added 12 articles. Data from these final 36 articles were indexed in a spreadsheet for analysis.

Article titles and summaries are presented in multiple tables in Chapter 4. Findings about the measurement of EF, the type and nature of the health behaviors, the temporal window between the measurement of EF and the measurement of health behavior, as well as the theoretical explanations for the relationship between health behavior and EF, are explored in these chapters.

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Figure 1. Study population

Table 1. Demographic characteristics for Baltimore, Maryland, and the United States from 2000 Census.

	Baltimore	Maryland	United States
General population			
Total population	651,154	5,296,486	281,421,906
% Female	53.4	51.7	50.9
% Persons ≥ 18 years	75.2	74.4	74.3
% Persons ≥ 65 years	13.2	11.3	12.4
Caucasian	32.6	65.4	77.1
Black or African American	65.2	28.8	12.9
Housing characteristics			
Households	300,477	1,980,859	105,480,101
% Persons living in households	96.0	97.5	97.2
Persons per household	2.42	2.61	2.59
% Owner-occupied housing unit	50.3	67.7	66.2
% householders ≥ 65 years	11.3	8.1	9.2
Socio-demographic characteristics			
% of individuals ≥ 25 years with less than high school degree	31.6	16.2	19.6
% of individuals ≥ 25 years with high school degree	28.2	26.7	28.6
% of individuals ≥ 25 years with greater than high school degree	40.2	57.1	51.8
% of individuals ≥ 16 years unemployed	6.0	3.2	3.7
Per-capita income	\$16,978	\$25,614	21,587
% Individuals below poverty	22.9	8.5	12.4
% Individuals ≥ 65 years below poverty line	18.0	8.5	9.9
% Individuals with public assistance income	7.3	2.4	3.4

Source: U.S. Census Bureau, 2000

Table 2. Demographic characteristics of original BMS population and final population used in analysis.

	Original population (N=1143)	Final population (N=926)	p-value*
Age, years			
50-64	48.28	72.46	0.0044
65-72	51.72	27.54	
Gender			
Male	35.98	33.91	0.5650
Female	64.02	66.09	
Race			
White	42.06	56.26	0.0002
African American	49.53	39.74	
Other	8.41	4.00	
Education, years			
< 12	37.93	13.17	0.0002
12	34.48	20.63	
13-15	6.90	21.17	
16	10.34	13.61	
17+	10.34	31.43	
Work status			
Work full time	40.38	44.10	0.0022
Work part time	11.74	19.50	
Other	47.89	36.40	
Marital status			
Married	47.00	50.65	0.3340
Unmarried	53.00	49.45	
Household wealth (income+assets), mean (range \$-38,500 - \$50,490,000)	\$245,603.00	\$471,142.00	0.053 [†]

* P-value of chi-square statistic.

[†] P-value from t-test.

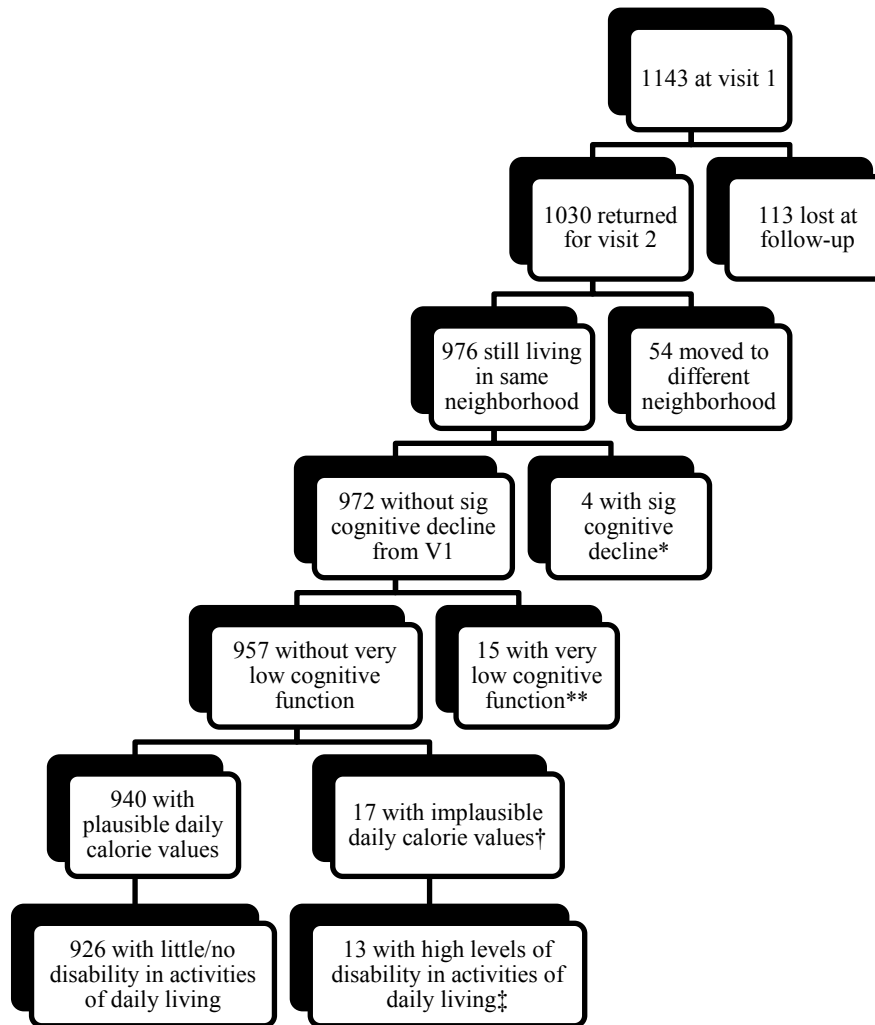
Table 3. Individual level data collection.

	Visit 1 (2001-2002)	Visit 2 (2002-2003)
Executive function	X	X
Smoking	X	
Alcohol consumption	X	
Physical activity		X
Dietary intake		X

Table 4. Components of dietary intake index. All amounts are on a per-day basis.

Component	Criteria for maximum score (10)	Criteria for minimum score (0)	Other scores
Grain consumption	6-11 servings	0 servings	Scored proportionately
Vegetable consumption	3-5 servings	0 servings	Scored proportionately
Fruit consumption	2-4 servings	0 servings	Scored proportionately
Milk consumption	2-3 servings	0 servings	Scored proportionately
Meat consumption	2-3 servings	0 servings	Scored proportionately
Total Fat	$\leq 30\%$ of total calories	$\geq 45\%$ of total calories	Scored proportionately
Saturated Fat	$\leq 10\%$ of total calories	$\geq 15\%$ of total calories	Scored proportionately
Cholesterol	≤ 300 milligrams (mg)	≥ 450 mg	Scored proportionately
Sodium	$\leq 2,400$ mg	$\geq 4,800$ mg	Scored proportionately
Variety	≤ 8 different items	≥ 3 different items	Scored proportionately

Figure 1. Study population



*Defined as scoring 1.5 standard deviations or more from the population mean of both the Trail Making test and the Stroop test, based on a similar protocol used by the study administrators.

**Defined as scoring 2 standard deviations or more below the population EF mean

†9 reported daily calories greater than 5000 and 8 who reported fewer than 500 daily calories

‡Defined as indicating the need for help or being unable to complete more than one activity of daily living (bathing, dressing, eating, walking across a small room, grooming, transferring from chair to a bed, using the toilet)

CHAPTER 3: EXECUTIVE BEHAVIOR AND HEALTH BEHAVIOR IN OLDER ADULTS

Abstract

Introduction: A growing field of public health research focuses on understanding and harnessing the complex cognitive processes involved in health behavior as older adults navigate the environments of their daily lives. Past studies have looked at the relationship between executive function (EF) and specific health behaviors, but none to date have considered an overall measure of health behavior.

Objective: To investigate the association of EF with the “big four” health behaviors and to test the hypothesis that EF would be associated with overall health behavior score among older adults.

Methods: Data collected from the Baltimore Memory Study on 926 community-dwelling persons aged 50 to 70 years in Baltimore, MD were used in multiple linear regression analysis. Health behavior data collected included measures of dietary intake, physical activity, smoking, alcohol consumption. A neurobehavioral battery of EF tests were used to create an overall measure of EF. Sociodemographic variables, including age, gender, race, years of education, work status, and marital status were entered into multiple variable linear regression models predicting each of four health behaviors as well as a measure of overall health behavior.

Results: Analysis detected a small but positive association between EF score and overall health behavior after controlling for several sociodemographic factors. Analyses from the sub-component health behaviors that comprised the overall health behavior score suggest that EF is also associated with physical activity and smoking but not with dietary intake or alcohol consumption.

Conclusion: These findings add to building evidence that EF may play a role in the implementation and maintenance of healthy behaviors in older adults and suggest that

EF may extend the ability to maintain into older age. Further research is needed to better understand this relationship between executive abilities and health behavior, especially for specific health behaviors and decisions.

Introduction

The United States is at the beginning of a demographic shift in which the proportion of older adults will swell by 138% from 2000 to 2050. By 2050, one in five Americans will be age 65 or older. Even more dramatically, the proportion of the “oldest old” – those over the age of 85 – will grow 377% by 2050. Healthcare researchers predict that this shift will have powerful economic, societal, social support and healthcare system implications (Goulding et al., 2003).

Much of this shift is attributed to the extended life expectancy brought about by advances in healthcare and breakthroughs in medicine. As a result, infectious disease as a major cause of mortality has been replaced by chronic disease such as heart disease, cancer, and stroke. Chronic disease currently accounts for seven of top ten causes of death in the United States (Centers for Disease Control and Prevention, 2013). The prevalence of chronic disease and multiple chronic diseases increases with age, and the proportion of middle-aged and older adults with multiple chronic conditions has increased over the past 10 years (Freid et al., 2012) but health experts assert that this fate is not inevitable. Evidence suggests that poor health does not have to be part of growing older (Centers for Disease Control and Prevention, 2010).

In this vein, member nations of the World Health Organization recently set a new goal of reducing premature mortality from chronic disease by 25% by 2025 and adopted a new set of chronic disease policies to promote healthy aging and wellbeing. Part of these goals for older adults target the reduction of tobacco use, harmful use of alcohol, unhealthy diet, and physical inactivity (World Health Organization, 2012), four “modifiable lifestyle factors” that have been shown to account for nearly 40% of annual deaths in the United States (Mokdad et al., 2004).

Unlike the prevention of many infectious diseases that require a one-time behavior for treatment and prevention (e.g., vaccination), the behaviors necessary to prevent and treat chronic disease are acknowledged to be more difficult to change and maintain. Hall and Fong (2007) explain that while healthy behaviors are associated with many long-term benefits and minimal long-term costs, they often have many short-term costs and relatively fewer short-term benefits. Navigating this “now vs. later” dilemma requires individuals to effortfully regulate their behavior to meet long-term goals and to maintain them over a lifetime. The capacity to do so depends upon the convergence of biological, cognitive, and social factors (Hall & Fong, 2007b).

A growing field of research in public health focuses on understanding and harnessing the complex cognitive processes involved in health behavior as individuals navigate the environments of their daily lives. Executive function (EF) is one such cognitive resource and has been the focus of recent attention in public health research (Dunn, 2010; Williams & Thayer, 2009)

Executive function the set of high-order neurocognitive processes emanating from the brain’s prefrontal cortex that are necessary to make choices and to engage in purposeful, goal-directed, and future-oriented behavior (Cummings, 2007; Gazzaley A, 2007). This includes planning, implementing, and monitoring, the regulation of internal processes such as thoughts, emotions, and behaviors, and the ability to override an automatic reflex or response in order to increase the potential for a better result in the future (Royall et al., 2002). Denkla (1994) suggests that the underlying theme of EF is the attention and intention of the future, and Barkley (2004) describes an executive act as one

directed toward oneself that functions “to change one’s behavior in order to change one’s future” (p. 304).

Executive function has been linked with significant variance in all-cause mortality (Duff et al., 2009; Hall et al., 2009) and shown to predict survival from chronic illness (cardiovascular conditions, diabetes, and cancer) among initially healthy older adults (Hall et al., 2010). It has also been shown to predict important health behaviors, including treatment adherence (Insel et al., 2006), substance use (Hall et al., 2006), stress regulation (Williams et al., 2009), rehabilitation behaviors (Solberg Nes et al., 2009), physical activity (Hall, Elias, et al., 2008), and eating behaviors (Hall, Fong, et al., 2008). Among the suggested explanations for these findings is that the self-regulatory capacities associated with EF – such as planning, monitoring behavior, making decisions and resisting tempting situations – enable the “consistent enactment of healthy behavioral patterns over the lifespan,” (Hall et al., 2010, p. 124) that lead to better health.

Past studies have looked at the relationship between EF and specific health behaviors, but none to date have considered an overall measure of health behavior. To investigate the association between EF and a measure of overall health behavior in a community-dwelling population of older adults, this study used data from two visits of the Baltimore Memory Study collected from 2001 to 2003. Overall health behavior was characterized by creating a composite score comprising four health behaviors: 1) number of cigarettes smoked daily; 2) average number of drinks consumed on days when drinking; 2) an index of healthy eating covering major dietary components; 3) an index of physical activity and physical activity intensity. The purpose of this analysis was to

investigate the association of EF with the “big four” health behaviors as well as to test the hypothesis that EF would be associated with overall health behavior score.

Methods

Study Population

Data for this study were obtained from the Baltimore Memory Study (BMS), a multilevel longitudinal cohort study of risk factors for cognitive decline in urban-dwelling older adults living in Baltimore, Maryland. Participants from this study were recruited for the original study from 81 contiguous neighborhoods in Baltimore City, Maryland. Eligibility criteria included being between ages 50 and 70 and having lived in Baltimore City for at least five years. Details about recruitment and study design have been reported elsewhere (Schwartz et al., 2004). Of the 1403 recruited and scheduled for an appointment, 1,143 (81.5%) were enrolled and subsequently tested at the study’s research clinic between May 2001 and September 2002 (visit 1). Participants were invited to return for four additional visits between 2002 and 2012. A total of 1,032 participants (90% of the initial study population) completed a second visit between October 2002 and December 2003 (visit 2). Average length between visits was 15.6 months.

This study was approved by the Committee for Human Research of the Johns Hopkins Bloomberg School of Public Health. All participants provided written, informed consent before testing and were paid \$50 for their participation in each visit.

This analysis included only the individuals who participated in both visit 1 and visit 2 and who lived in the same neighborhood during both visits (N=976). Four participants were removed from analysis who demonstrated significant cognitive decline

from visit 1 to visit 2 (scoring 1.5 standard deviations or more from the population mean of both the Trail Making test and the Stroop test, based on a similar protocol used by the study administrators). Seventeen participants were removed from analysis because they had biologically implausible values for Block Food Frequency Questionnaire (nine reported daily calories greater than 5000 and eight who reported fewer than 500 daily calories). One participant was removed for indicating a biologically implausible number of average drinks per day. Because this study is most interested in the association of EF and health behavior in a high-functioning population, participants who scored two standard deviations or lower than the population mean EF score were removed from this analysis (n=15). Because physical functioning is directly linked to ability to maintain healthy behavior, participants who scored a one or greater on the Katz Activities of Daily Living Index (indicating the inability or need for help to perform at least one activity of daily living (e.g., bathing, dressing, eating) were removed from analysis; 13 individuals were removed for this reason. This left 926 participants in the final analysis. Figure 1 displays the breakdown of the final analysis population.

Participants in the final sample were compared to those who began the study at visit 1. Table 1 presents demographic characteristics of the initial population and the final population. Participants in the final population were more likely than those in the original population to be younger ($p=0.004$), white ($p=0.002$), to be more highly educated ($p=0.002$), to work full or part time ($p=0.002$), and to have greater household wealth ($p=0.053$). There were no statistical differences in marital status or percent female.

Data Collection

Data for this analysis come from neurobehavioral testing and structured interviews conducted during visit 1 and visit 2 described above.

Measuring Health Behavior

The outcome measure is a composite score of overall health behavior. To create this score, we created measures of four health behaviors: dietary intake, physical activity, smoking, and alcohol consumption.

Smoking and alcohol consumption were assessed during the structured interview of visit 1. To assess smoking behavior, participants were asked whether they had ever smoked 100 cigarettes, whether they currently smoke, and the average number of cigarettes they smoke per day. A measure was created of the average number of cigarettes smoked per day; non-smokers were listed as smoking 0 cigarettes per day.

Alcohol consumption was also measured during this visit 1 structured interview.

Participants were asked whether they had consumed at least one drink in the past month, the average number of drinks per week or month that they consume, the number of drinks they consume on days that they drink, and the number of days in the past month that they consumed four or more (for women) or six or more (for men) drinks. A measure was calculated to represent the average number of drinks consumed on the days when the participant drank. Non-drinkers were listed as drinking 0 drinks.

Dietary intake and physical activity were measured during visit 2. Before reporting for visit 2, participants were asked to complete the Block 98.2 Food Frequency Questionnaire (Block, Hartman, & Naughton, 1990). This instrument has been validated for a variety of populations (Boucher et al., 2006; Johnson, Herring, Ibrahim, & Siega-Riz, 2007) and has been reported to be highly reliable (Hartman et al., 1996; Leighton,

Neugut, & Block, 1988). To provide an overall indication of dietary intake, an eating index was created based on the 1995 Health Eating Index (HEI), a measure of dietary quality used by the United States Department of Agriculture (USDA) to assess conformance to federal dietary guidelines and to monitor the diet quality of the U.S. population (U. S. Department of Agriculture, 2010). The 1995 overall HEI score (representing the dietary guidance at the time of measurement) is the sum of 10 dietary components, five regarding adherence to the USDA food pyramid and five assessing intake of total fat, saturated fat, cholesterol, sodium, and dietary variety. Calculation of this dietary index followed the HEI method, with the exception of the dietary variety construct, which measures the degree to which a person's diet varies. The HEI variety score is typically calculated by summing the number of different foods (those that contribute at least one-half of a serving in a food group) (U. S. Department of Agriculture, 2010) consumed in one day. These data were not available, however, so a measure was created that summed the number of different solid foods consumed in one day. HEI scores greater than 80 points are considered by USDA to be "good." Scores between 51 and 80 are considered to "need improvement," and scores below 51 are classified as "poor." (Basiotis, Carlson, Gerrior, Juan, & Lino, 2002).

Physical activity was assessed during the visit 2 structured interview using the Yale Activity Survey for Older Adults (YPAS) (Dipietro, Caspersen, Ostfeld, & Nadel, 1993), an instrument used widely with the older adult population, particularly because its inventory includes low-intensity activities. This instrument has been validated and possesses a high degree of internal consistency (Young, Jee, & Appel, 2001). The instrument comprises two sections. The first section asks about time spent (in hours per

week) in work, exercise, and various recreational activities within the past month. The second section assesses time spent in vigorous activity, leisurely walking, and general movement, standing, and sitting (in hours per week). From the second section, index scores are calculated as the product of the frequency of the respective activity (e.g., once per week), the duration of activity (e.g., 20 minutes), and an activity intensity score ranging from 1 to 5 (Dipietro et al., 1993). A Total Activity Index was calculated as the sum of the vigorous activity index score, leisurely walking index score, moving index score, standing index score, and sitting index score. Dipietro, Caspersen, Ostfeld, & Nadel (1993) describe this measure as an individual's total physical activity in a week with consideration to intensity.

An overall health behavior composite score was calculated from the measures of the four health behavior component scores (dietary intake, physical activity, smoking, and alcohol consumption). First, the scores of smoking and alcohol consumption measures were reversed so that higher scores for all component scales indicate healthier behavior. Next, each behavior score was transformed to a 25-point scale (with 25 representing healthier behavior). Behavior scores were then summed for a composite score ranging from 0 to 100, with 100 being the healthiest possible score.

Measuring Executive Function

Executive function was also measured during the structured interview using three validated neurobehavioral instruments. The Trail Making test was selected to measure an aspect of EF known as set-shifting, the ability to go back and forth between tasks or mental sets (Miyake, Emerson, & Friedman, 2000) as well as measuring attention, processing speed, and mental flexibility (Strauss, Sherman, & Spreen, 2006). The test is a

connect-the-dots exercise. In Test A, participants are given a piece of paper with 25 numbers and are asked to draw a line from one target to the next in numerical order, providing a measure of attention and psychomotor speed. Test B includes targets with both numbers and letters; participants are asked to connect the targets alternating between numbers and letters (i.e., 1, A, 2, B, 3, C, etc.) Time taken to complete the test is the performance metric. To measure EF, the score from Test A is subtracted from the Test B score.

The Stroop test is one of the oldest and most widely used measures for assessing attention and response inhibition, the ability to attend to a goal and to inhibit a habitual response in favor of a less used response. The test generally comprises three parts, each of which requires a participant to read a list of colors. The last section assesses the examinee's ability to view a list of colors, with each word printed in a colored ink that is different than the word it represents (e.g., the word red printed in green ink). Examinees are asked to identify the color of the ink rather than reading the word aloud. The time and accuracy in which this is accomplished is compared with the individual's scores from previous sections in which the individual reads words printed in ink that was black or that matched the color word (Strauss et al., 2006).

The Purdue Pegboard test (model 32020; Lafayette Instrument Corporation, Lafayette, IN; LIC 1999) is generally used as a measure of eye-hand coordination and manual dexterity but also taps cognitive processing speed and attentional control (Strauss et al., 2006). Participants sit in front of a pegboard and a cup of pins and are given instructions about placing the pins into the pegboard in a particular order using their dominant hand, then their dominant hand, then both hands together. Elapsed time is the

measure of performance. In an assembly task, participants are given several types of materials (pins, washers, and collars) with instructions to assemble an arrangement of these materials in a specific order. An assemblies score is calculated by tallying the number of correctly placed pins or assemblies. A measure of EF is calculated by subtracting the test score while using both hands from the assemblies score; this removes the aspect of the task related to manual dexterity, thereby isolating the aspect of the task that taps cognitive processing speed and attentional control (Strauss et al., 2006).

Because the health behavior composite score drew from data collected at both visit 1 and visit 2, it was desirable for the EF measure to be representative of EF at both time periods. Therefore, an EF average score was calculated from both visits. To do so, z-scores of each EF test were calculated for visit 1 and visit 2. Next, the visit 1 score and visit 2 score for each respective EF test were averaged, resulting in an averaged single score for each of the three tests. Finally, the three scores were averaged to arrive at a final EF score. For behaviors measured at only one time, the EF score from the corresponding visit was used.

Measuring Other Covariates

Gender was self-reported during the visit 1 interview. Birthdates were captured during the visit 1 interview and dates of each visit were recorded for each respondent, enabling the calculation of age at each visit for each respondent. Marital status was captured as a self-report question at visit 1 and a dichotomized measure was created of those who were married vs. those who were not married. Education was created using the self-report of highest educational attainment as reported during the visit 1 interview and described in the number of years of education. Body mass index was calculated

using measurements taken during visit 1 by dividing weight in pounds by the square of height in inches and multiplying by 703.

Analysis

We used multiple linear regression to examine the relationship between EF and health behavior in older adults. Data analysis was performed in SAS version 9.2 (SAS Institute, Cary, NC).

Analysis began by examining univariate distributions of the outcome and major variables of interest. Next, a series of bivariate analyses examined the relationship between the outcome variables (health behavior scores) and the main predictor (EF), as well as between the outcome variable and a variety of sociodemographic variables. Variables with a p-value greater than 0.25 were removed from multiple linear regression modeling, with the exception of household wealth, which was removed from the final regression models to avoid collinearity with education, another socioeconomic status (SES) measure with a stronger theoretical association with EF.

A final model was built by beginning with a base model of the main predictor of interest (EF score) and control variables (age, gender, race). Variables were added to the model if they were independently associated with the health behavior outcome, if they were theoretically relevant, or if the addition of the variable substantially changed the relationship between EF and behavior score. Variables with nonsignificant coefficients were removed from each model for the sake of parsimony, with the exception of race, which significantly affected the relationship between health behavior and EF and is also known to be associated with EF in this population (Schwartz et al., 2004). To consider

effect modification, interaction terms between all combinations of variables were created and tested in the final model.

All models were examined for linearity, normality, multi-collinearity, and heteroscedasticity and indicators of model fit using adjusted variable plots, distribution of residuals, and variance inflation factors. Cook's distance measures were examined to identify the existence of influencers, outliers, and high leverage observations.

Results

Description of Study Participants

A total of 926 participants were included in this analysis. Average age was 60.6 years (range: 51.0 – 72.3 years). Women comprised 66% of the study population. More than half of the sample were white (56%), 40% were African American, and 4% were Asian, Hawaiian, Native American, or a different race. Thirteen percent had less than 12 years of education, and 45% had 16 or more years of education. Forty-four percent of participants worked full-time. Average household wealth (the sum of income and assets) was \$471,142 (range: -\$38,500—\$ 50,490,000). Executive function scores ranged from -1.99 to 1.63, with a mean of 0.019. Other overall descriptive characteristics are presented in Table 2.

Healthy Eating Index scores ranged from 31.4 to 94.2, with a mean of 65.6 (categorized by the USDA as “needs improvement”), slightly lower than the national average score for older adults of 66.6 (Centers for Disease Control and Prevention, 2008). Sixteen percent of participants had an HEI score categorized as “good,” 69% had a score categorized as needs improvement,” and 14% scored in a range categorized as “poor.” This distribution is nearly identical to the estimated distribution with older adults

nationwide during the same time period in which 17% rated as “good,” 68% labelled “needs improvement, and 14% categorized as “poor” (Centers for Disease Control and Prevention, 2008).

Approximately 37% of participants reported not having had any alcoholic drinks within the past month. Of those who drank within the last month, 28% reported having an average of 0.5 to 1 drinks on typical drinking days. Eighty-one percent of participants reported to be non-smokers. Average YPAS activity index score was 46.6 (range: 8.0 – 130.0). Overall average health behavior score ranged from 43.3 to 97.7, with a mean of 73.8.

Table 2 presents data on sociodemographic variables and health behaviors stratified by EF scores. Individuals in the highest EF score group were more likely to be female, to be below 65 years of age, to be white, to have 16 or more years of education, and to be working full time. They were more likely to be non-smokers and to be current drinkers. 25% of participants in the highest EF score group had HEI scores categorized as “good,” and 44% had a BMI in the normal range.

Those in the lowest EF score groups were more likely to be female, African American, to have 12 or fewer years of education, and to be in the “other” work status category. They were more likely to be a non-smoker and current drinker. Thirteen percent of participants in the lowest EF score group had HEI scores in the “good” category, and 26% had a BMI in the normal range.

Health Behavior Scores

Table 3 presents data on health behavior scores and key sociodemographic variables. For HEI scores, women, those over 65 years of age, and those in the white and

“other” race categories had higher HEI scores than did men, those younger than 65 years, and African American participants. Gradient patterns were detected by education, EF scores, and household wealth, with those of more years of education, higher EF scores, and greater household wealth having higher mean HEI scores than those in lower categories. Individuals working part time had higher HEI scores than did those in other work categories.

For physical activity, men, those under 65 years of age, those working part time, and those in the white and “other” race category had higher mean YPAS activity scores than did other categories. Those with an EF score between 0 and 1, those with 17 or more years of education, and those in the highest quartile of household wealth had the highest mean YPAS activity scores, as compared with other EF, education, and household wealth categories, respectively.

For both smoking and drinking behaviors, women, those over 65, and African Americans consumed the fewest mean number of cigarettes and drinks, than did those in other categories. For smoking, those in the highest education, EF score, and household wealth categories smoked the fewest mean number of cigarettes of all groups. For drinking, however, those with the greatest amount of education and EF categories had the highest mean number of drinks on drinking days.

For overall health behavior score, women, those under the age of 65, those in the “other” race category, and those who worked part-time had the highest mean overall health behavior score. A gradient pattern was seen by education, EF scores, and household wealth, with those of more years of education, higher EF scores, and greater

household wealth having higher mean health behavior scores than those in lower categories.

Relationship between Executive Function and Health Behavior

To examine the association of EF and health behaviors while controlling for sociodemographic variables, multiple variable linear regression was conducted with each health behavior as the dependent variable. Table 4 presents full and final multivariate linear regression models for each health behavior and for the overall health behavior score.

The final model for HEI score indicates that EF was not significantly associated with HEI score, but age and years of education were positively associated with HEI score. Women had a mean HEI score 4.6 points higher than men ($p < .0001$). African American participants had a mean HEI score 2.6 points lower than did all other participants ($p = .003$). Body mass index was negatively associated with HEI score; each one-point increase in BMI was associated with a .12 point decrease in HEI score ($p = .054$).

Executive function was significantly associated with a natural log-transformed YPAS activity index score; each one-unit increase (essentially a one-standard deviation increase) in EF was associated with a .06 point increase in log YPAS score ($p = 0.012$). Translated to the linear scale, this can be interpreted as 6% ($\exp(0.06) = 1.06$) greater YPAS score for a one standard deviation increase in EF. Women had a mean log YPAS score .09 points lower than did men ($p = 0.007$). Individuals working part time had a mean log YPAS score 0.09 points greater than those in other work categories ($p = 0.031$). Household wealth was positively associated with YPAS, and BMI was negatively

associated with YPAS. Executive function moderated the relationship of age and health behavior, indicating that the negative association between age and YPAS score diminishes with increased EF score. Figure 1 illustrates this effect modification.

The final regression model between EF and mean number of cigarettes smoked daily indicated that EF has a moderately statistically significant association with smoking; a one-unit increase in EF score was associated with 0.71 fewer cigarettes smoked daily ($p=0.057$). Age, education and BMI were negatively associated with cigarette consumption. Women smoked 1.51 fewer cigarettes daily than did men ($p=0.001$). African American participants smoked 1.65 fewer cigarettes daily than did other races ($p=0.006$). Statistically significant interaction terms indicate that gender modified the relationship between age and smoking status, with age having a weaker effect on number of daily cigarettes among women as compared to men. Another significant interaction term suggests that race modified the relationship between education and smoking status, with education having a weaker relationship with smoking among African Americans as compared to other races. Results from this analysis should be interpreted with caution, however, as the number of smokers within this population was small. Data are not presented here, but a logistic regression analysis predicting being a current smoker using the same independent variables produced similar results.

Results from the final regression model for alcohol consumption suggests that EF modifies the relationship between age and mean number of drinks consumed on a typical drinking day, indicating that the negative association between age and mean number of drinks diminishes with increased EF score. Figure 2 illustrates this effect modification.

Women consumed on average 0.73 fewer drinks than did men ($p<.0001$). Not having a spouse or partner was associated consuming 0.25 more drinks on drinking days ($p=0.02$). Another significant interaction term in this model indicates that gender modifies the relationship between race and drinking, with African American women drinking fewer drinks than did African American men ($p=0.0029$).

Executive function was statistically significantly associated with overall health behavior score. A one-unit increase in EF score was associated with a 0.83 point increase in overall health behavior score ($p=0.041$). Women had a mean health behavior score 1.69 points higher than men ($p=0.001$). Education was positively associated with overall health behavior score. Each one-year increase in years of education was associated with a 0.51 point increase in overall health behavior score ($p<.0001$), and a moderately significant interaction term indicated that EF modifies the relationship between age and health behavior score, suggesting a weaker negative relationship between age and health behavior score among those of higher EF. Figure 3 illustrates this effect modification.

Discussion

The aims of this study were to explore the association of EF with the health behaviors most associated with chronic disease and with an overall measure of health behavior. Our findings detected a small but positive association between EF score and overall health behavior in a sample of community-dwelling older adults after controlling for several sociodemographic factors. Analyses from the sub-component health behaviors that comprised the overall health behavior score suggest that EF is also associated with physical activity and is moderately associated with smoking but not with dietary intake.

Additionally, these findings point to EF as a moderately significant effect moderator in the relationship between age and overall health behavior, physical activity score, and alcohol consumption, suggesting that EF may extend the ability for older adults to maintain healthy behavior into older age. This is consistent with the findings of Hall, Fong, and Epp (2014) who looked at EF and a health behavior score comprised of physical activity and fatty food intake in an age-stratified sample. These authors reported that EF had stronger effects among older populations.

While there is no known research examining the association of EF and overall health behavior in this population, these findings were consistent with other similar research regarding a number of specific health behaviors. McAuley et al. (2011) reported that higher levels of EF and self-regulatory strategies were associated with adherence to an exercise program in older adults, mediated through exercise self-efficacy. Hall et al. (2006) reported that an association between EF, as measured by the Stroop test, and smoking and alcohol consumption in a community-based sample with mean age of 55 years but did not find an association between EF and physical activity. Taken together, the current findings add to building evidence that EF – as the biological measure of self-regulation capacity – may play a role in the implementation and maintenance of healthy behaviors.

Research revealing several important characteristics about this population should be considered when comparing these results to those of other studies of EF and health behavior. First, this population has a relatively large proportion of African Americans (39%) with moderate to high tibia lead levels (Shih et al., 2006), likely from lifetime cumulative environmental lead exposure. Tibia lead is associated with lower cognitive

functioning, including EF (Shih et al., 2006). Furthermore, research with this population has identified that living in neighborhoods characterized by a high level of psychosocial hazards (defined as stable and visible features of neighborhood environments that give rise to a heightened state of vigilance, alarm, or threat in residents) exacerbates the adverse effects of lead exposure in EF (Glass et al., 2009).

Strengths and Limitations

It must be acknowledged that the findings for overall health behavior score suggest a very small difference in health behavior score for each rather large increase in EF score (standard deviations), and these findings should be interpreted in light of the study's strengths and limitations. Strengths include a rich data set from a cross-section of urban older adults with wide range of socio-economic characteristics. The measure of EF used three well known, valid and reliable neuropsychological tests. Socioeconomic status was measured very carefully and fully for this population of older adults.

Study limitations should be considered in the interpretation of findings. One limitation is the use of self-reported health behavior data, especially for more complex questionnaires such as the Block Food Frequency Questionnaire and Yale Physical Activity Survey. Recall bias may be an issue in such data, especially among an older adult population with declining cognitive functioning. Using a more objective measure for physical activity, such as an accelerometer, would protect against such recall bias. At the time of this study (2000-2003), however, such technology was prohibitively expensive.

Another important limitation of this study is the cross-sectional nature of the analysis for an association that is known to be bi-directional. Because of the cross-

sectional nature of this analysis, we cannot say that it is an individual's EF that contributes to better health behavior. Indeed, a well-established literature supports the positive impact of physical activity, especially aerobic exercise, on cognitive performance (including EF) and points to potential anatomical changes and structural integrity of the brain brought about by physical activity (Colcombe et al., 2006; Erickson et al., 2011; Voss, 2010). It is worth noting, however, that older adults are less likely to engage in aerobic physical activity, which may mean that a cardiovascular explanation for the EF/physical activity relationship is less likely among this population.

Implications

Findings about EF and health behavior are especially salient for older populations, as EF, along with cognitive function in general, is known to decline with age (Brennan, Welsh, & Fisher, 1997; Royall, Palmer, Chiodo, & Polk, 2004). The bi-directional association between EF and health behavior may be considered to be a strength in its potential for public health intervention. Regardless of which comes first, it is encouraging news that health behavior and EF are associated. On one hand, this suggests that interventions aimed at increasing cognitive abilities in older adults – such as the Experience Corps program (Carlson et al., 2009) – may have additional and life-enhancing benefits in increasing health behavior, which in turn could fuel increases in cognitive function and sustain healthy aging. On the other hand, if health behaviors can be improved, this may increase cognitive function, which may in turn increase health behavior. This could be an upwardly spiraling cycle that could contribute meaningfully to healthy aging. The finding that EF moderates the relationship between age and health behavior further underscores this possibility.

Areas for Future Research

With only a handful of studies on EF and health behavior to date, there is much room for future research in this area. While this study showed a small association between EF and health behavior, more research is needed to understand this relationship.

A strong theoretical explanation exists for how self-regulatory aspects of EF can impact health behavior, but this study cannot address this. This type of research may be best done at a more micro level, examining EF, self-regulation and a single health behavior decision – perhaps in grocery store or vending machine choices.

This study found relatively small changes in health behavior for each one-unit change in EF, and those units were rather large (standard deviations). This may beg the question of whether small differences in EF within a “normal” range make a difference in overall health behavior.

Finally, this study of the relationship between EF and health behavior has been conducted in a population of older adults with a number of unique factors, including psychosocial neighborhood and environmental factors that could possibly contribute to differences in both EF and health behavior. While lead exposure and neighborhood has been reported to affect EF scores, no research investigating the mechanisms through which lead exposure might interact with neighborhood characteristics to affect health behavior. The weak association reported in this research may be in part due to an unknown mechanism at work in this population that may not be present in EF/health behavior studies in other populations of older adults. Future research could investigate these mechanisms, which may provide a cognitive lens to expand our understanding of race- and economic-based health disparities.

Conclusion

Using a sample of community-dwelling older adults from the BMS, we examined the relationship between EF and overall health behavior in older adults. Results indicate a small, but statistically significant association between EF and overall health behavior score, physical activity, and smoking, as well as moderately significant effect modification of EF on the relationship between age and overall health behavior, alcohol consumption, and physical activity. These findings add to building evidence that EF may play a role in the implementation and maintenance of healthy behaviors in older adults and suggest that EF may extend the ability to maintain into older age. Further research is needed to better understand this relationship between executive abilities and health behavior, especially for specific health behaviors and decisions.

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Table 1. Demographic characteristics of original BMS population and final population used in analysis

	Original population (N=1143)	Final population	p-value[‡]
Age, years			
50-64	48.28	72.46	0.0044
65-72	51.72	27.54	
Gender			
Male	35.98	33.91	0.5650
Female	64.02	66.09	
Race			
White	42.06	56.26	0.0002
African American	49.53	39.74	
Other	8.41	4.00	
Education, years			
< 12	37.93	13.17	0.0002
12	34.48	20.63	
13-15	6.90	21.17	
16	10.34	13.61	
17+	10.34	31.43	
Work status			
Work full time	40.38	44.10	0.0022
Work part time	11.74	19.50	
Other	47.89	36.40	
Marital status			
Married	47.00	50.65	0.3340
Unmarried	53.00	49.45	
Household wealth (income+assets), mean (range \$-38,500 - \$50,490,000)	\$245,603.00	\$471,142.00	0.053 [§]

[‡] P-value of chi-square statistic.

[§] P-value from t-test.

Table 2. Participant characteristics stratified by executive function score

	Overall, %	EF Score -2 to -1 (n=84), %	EF Score -1 to 0 (n=322), %	EF Score 0 to 1 (n=468), %	EF Score 1 to 2 (n=52), %	p**
Age, years						
50-64	72.46	39.29	64.60	81.41	94.23	<.0001
65-72	27.54	60.71	35.40	18.59	5.77	
Gender						
Male	33.91	30.95	34.16	34.83	28.85	0.78
Female	66.09	69.05	65.84	65.17	71.15	
Race/ethnicity						
White	56.26	13.10	37.58	73.08	90.38	<.0001
African American	39.74	79.76	57.14	24.36	5.77	
Other	4.00	7.14	5.28	2.56	3.85	
Education, years						
< 12	13.17	35.71	22.36	4.27	0.00	<.0001
12	20.63	23.81	25.16	17.31	17.31	
13-15	21.17	25.00	23.29	20.09	11.54	
16	13.61	3.57	9.32	17.31	23.08	
17+	31.43	11.90	19.88	41.03	48.08	
Work status						
Work full time	44.10	21.43	40.06	48.82	63.46	<.0001
Work part time	19.50	21.43	15.22	22.37	17.31	
Other	36.40	57.14	44.72	28.82	19.23	
Marital status						
Married	50.65	39.29	50.31	52.14	57.69	0.1217
Unmarried	49.45	60.71	49.69	47.86	42.31	
Household wealth (income+assets), mean (range \$-38,500 - \$50,490,000)	\$471,142	\$118,055	\$548,188	\$486,448	\$426,963	0.6033 ++

^{**} P-value of chi-square statistic.

^{††} P-value from analysis of variance.

	Overall, %	EF Score -2 to -1 (n=84), %	EF Score -1 to 0 (n=322), %	EF Score 0 to 1 (n=468), %	EF Score 1 to 2 (n=52), %	p**
Tobacco use						
Non-smoker	80.99	64.29	80.43	83.33	90.38	0.0002
Current smoker	19.01	35.71	19.57	16.67	9.62	
Alcohol consumption						
Non-drinker	37.04	61.90	46.27	27.35	26.92	<.0001
Current drinker	62.96	38.10	53.73	72.65	73.08	
Healthy Eating Index						
Good, >80	16.47	13.10	11.25	19.70	25.00	0.01
Needs Improvement, 51-80	69.12	70.24	71.25	67.88	65.38	
Poor, <51	14.41	16.67	17.50	12.42	9.62	
Yale Activity Index, mean (range 8-130)	46.60	37.61	44.92	49.38	46.42	<.0001 ‡‡
Overall health behavior score ^{§§} , mean (range 43.3-97.7)	73.79	70.84	73.00	74.72	75.02	<.0001 ***
Body mass index (kg/m ²) category						
Normal, (18.5-24.9)	25.70	16.67	20.50	28.85	44.23	<.0001
Overweight (25-29.9)	33.15	38.10	29.81	34.62	32.69	
Obese (≥ 30.0)	41.14	45.24	49.69	36.54	23.08	

^{††} P-value from analysis of variance.

^{§§} Overall health behavior score is a composite score calculated by summing the four individual behavior scores after each was transformed to a 25-point scale. The scores of smoking and alcohol consumption measures were reversed so that for all component scales, higher scores indicate healthier behavior. A score of 100 is the healthiest possible score.

^{***} P-value from analysis of variance.

Table 3. Means (and ranges) for health behavior scores

	HEI score Mean (range)	Yale Activity Index score Mean (range)	Cigarettes per day Mean (range)	Average drinks on drinking days Mean (range)	Overall health behavior score Mean (range)
Gender					
Men (n=314)	63.12 (34.30- 94.21)	50.54 (8.00- 130.00)	3.82 (0.00-50.00)	1.89 (0.00-16.00)	72.83 (43.30- 94.50)
Women (n=613)	66.96 (31.39- 93.62)	44.57 (8.00- 128.00)	2.13 (0.00-40.00)	0.96 (0.00-12.00)	74.29 (50.20- 97.70)
Age, years					
50-64 (n=671)	65.20 (31.39- 94.21)	48.30 (8.00- 130.00)	3.02 (0.00-50.00)	1.29 (0.00-10.00)	73.87 (43.30- 94.90)
65-72 (n=255)	66.85 (34.03- 92.37)	42.12 (8.00- 126.00)	1.85 (0.00-40.00)	1.25 (0.00-16.00)	73.60 (48.30- 97.70)
Race					
White (n=522)	67.38 (34.03- 94.21)	48.42 (8.00- 130.00)	2.81 (0.00-40.00)	1.48 (0.00-16.00)	74.37 (44.90- 97.70)
African American (n=368)	62.97 (31.39- 92.37)	43.62 (10.00- 128.00)	2.55 (0.00-50.00)	0.98 (0.00-10.00)	72.84 (43.30- 96.70)
Other (n=37)	68.07 (40.80- 92.30)	50.43 (9.00- 100.00)	2.62 (0.00-20.00)	1.36 (0.00-12.00)	75.16 (53.20- 88.90)
Education, years					
< 12 (n=122)	60.02 (34.03- 87.81)	43.52 (9.00- 128.00)	5.21 (0.00-40.00)	1.29 (0.00-16.00)	70.44 (44.90- 94.10)
12 (n=191)	62.45 (31.39- 90.66)	42.92 (8.00- 126.00)	3.53 (0.00-50.00)	1.23 (0.00-12.00)	71.82 (43.30- 94.50)
13-15 (n=196)	64.75 (34.78- 93.62)	44.10 (9.00- 116.00)	2.44 (0.00-30.00)	1.16 (0.00-6.00)	73.25 (50.40- 92.30)
16 (n=126)	68.12 (38.33- 92.30)	49.12 (9.00- 130.00)	2.00 (0.00-40.00)	1.25 (0.00-6.00)	75.32 (55.80- 96.70)
17+	69.68	50.88	1.57	1.39	76.21

	HEI score Mean (range)	Yale Activity Index score Mean (range)	Cigarettes per day Mean (range)	Average drinks on drinking days Mean (range)	Overall health behavior score Mean (range)
(n=291)	(34.30-94.21)	(8.00-126.00)	(0.00-40.00)	(0.00-6.00)	(48.70-97.70)
Executive function score					
-2 to -1 (n=84)	63.96 (41.25-92.37)	37.61 (9.00-81.00)	4.43 (0.00-40.00)	1.00 (0.00-10.00)	70.84 (53.00-83.90)
-1 to 0 (n=322)	63.81 (31.39-90.92)	44.92 (8.00-128.00)	2.74 (0.00-50.00)	1.23 (0.00-16.00)	73.00 (43.30-96.70)
0 to 1 (n=468)	66.86 (34.03-94.21)	49.38 (10.00-130.00)	2.49 (0.00-40.00)	1.35 (0.00-6.00)	74.72 (50.20-97.70)
1 to 2 (n=52)	68.95 (40.18-92.30)	46.42 (8.00-95.00)	1.56 (0.00-30.00)	1.39 (0.00-6.00)	75.02 (57.80-88.70)
Work status					
Work full time (n=407)	65.26 (36.58-94.21)	48.68 (8.00-130.00)	2.60 (0.00-40.00)	1.29 (0.00-8.00)	74.17 (48.70-94.50)
Work part time (n=180)	67.66 (34.30-91.66)	49.74 (10.00-126.00)	2.42 (0.00-40.00)	1.27 (0.00-6.00)	75.11 (50.20-97.70)
Other (n=336)	65.01 (31.39-93.24)	42.56 (8.00-118.00)	2.99 (0.00-50.00)	1.26 (0.00-16.00)	72.64 (43.30-94.90)
Household wealth (income + assets), dollars					
Quartile 1 (n=231)	62.86 (31.39-93.62)	42.14 (9.00-128.00)	4.68 (0.00-40.00)	1.21 (0.00-10.00)	71.20 (48.70-94.10)
Quartile 2 (n=231)	65.24 (34.03-92.37)	45.36 (9.00-126.00)	2.19 (0.00-40.00)	1.00 (0.00-12.00)	73.96 (53.20-96.70)
Quartile 3 (n=232)	65.44 (34.30-91.38)	47.38 (8.00-118.00)	2.63 (0.00-50.00)	1.29 (0.00-8.00)	73.95 (43.30-94.90)
Quartile 4 (n=232)	68.91 (35.52-94.21)	51.26 (8.00-130.00)	1.43 (0.00-40.00)	1.60 (0.00-16.00)	75.90 (44.90-97.70)

Table 4. Regression coefficients and p-values for full and final linear regression models of health behaviors

	HEI score β Coefficient (p-value)		Yale Activity Index score β Coefficient (p-value)		Cigarettes per day β Coefficient (p-value)		Average drinks on drinking days β Coefficient (p-value)		Overall health behavior score⁺⁺⁺ β Coefficient (p-value)	
	Full model	Final model	Full model	Final model	Full model	Final model	Full model	Final model	Full model	Final model
Intercept	54.211 ($<.0001$)	54.324 ($<.0001$)	4.029 ($<.0001$)	4.126 ($<.0001$)	13.430 ($<.0001$)	9.298 ($<.0001$)	2.372 ($<.0001$)	1.776 ($<.0001$)	67.195 ($<.0001$)	71.356 ($<.0001$)
Executive function z-score	-0.3173 (0.6385)	-0.386 (0.560)	0.0807 (0.009)	0.0825 (0.0004)	-0.661 (0.081)	-0.711 (0.057)	0.077 (0.541)	0.058 (0.516)	1.004 (0.026)	0.834 (0.041)
Age in years, centered	0.230 (0.004)	0.239 (0.001)	-0.009 (0.001)	-0.010 (0.001)	-0.213 ($<.0001$)	-0.291 ($<.0001$)	0.004 (0.878)	0.005 (0.964)	0.102 (0.038)	0.086 (0.054)
Gender										
Male	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)
Female	4.616 ($<.0001$)	4.656 ($<.0001$)	-0.095 (0.005)	-0.094 (0.005)	-1.556 (0.001)	-1.510 (0.001)	-0.903 ($<.0001$)	-0.727 ($<.0001$)	1.664 (0.002)	1.692 (0.001)
Marital status										
Married	1.0 (ref)	-	1.0 (ref)	-	-	-	1.0 (ref)	1.0 (ref)	-	-
Not married	-0.823 (0.317)	-	0.008 (0.805)	-	-	-	0.227 (0.029)	0.245 (0.002)	-0.615 (0.218)	-
Race										
White	1.0 (ref)	1.0 (ref)	1.0 (ref)	-	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	1.0 (ref)	-

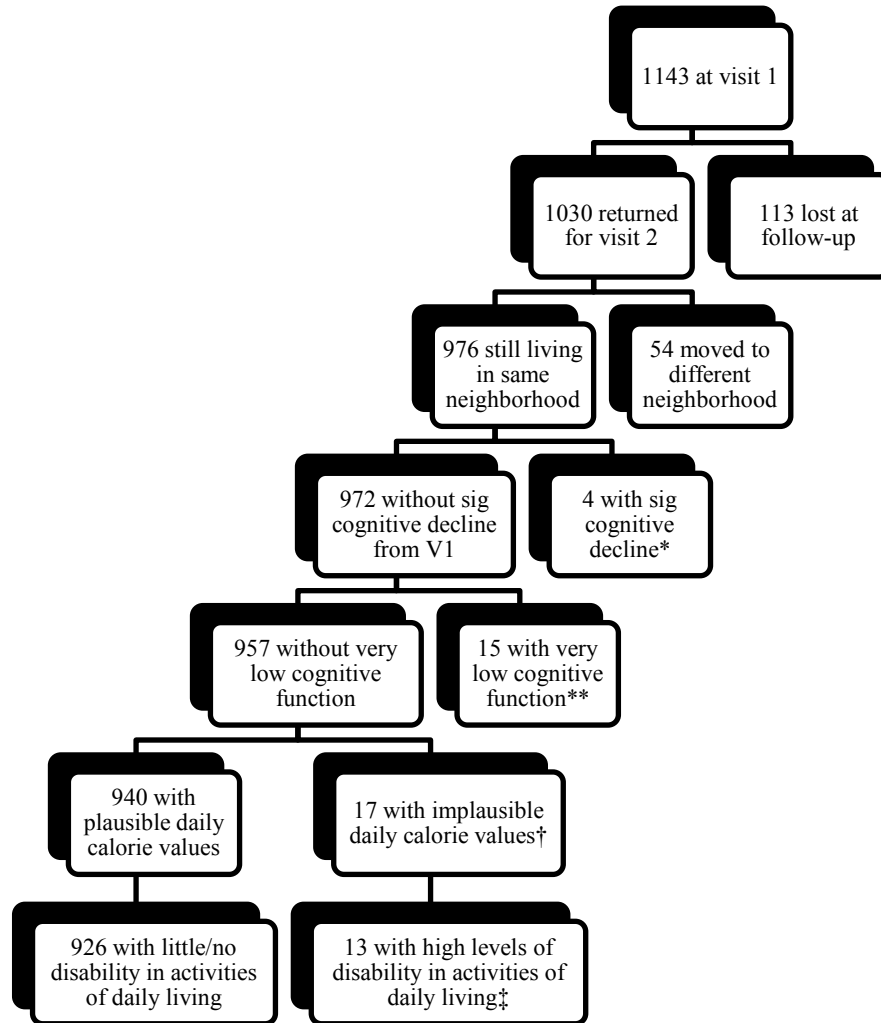
⁺⁺⁺Overall health behavior score is a composite score calculated by summing the four individual behavior scores after each was transformed to a 25-point scale. The scores of smoking and alcohol consumption measures were reversed so that for all component scales, higher scores indicate healthier behavior. A score of 100 is the healthiest possible score.

	HEI score β Coefficient (p-value)		Yale Activity Index score β Coefficient (p-value)		Cigarettes per day β Coefficient (p-value)		Average drinks on drinking days β Coefficient (p-value)		Overall health behavior score⁺⁺⁺ β Coefficient (p-value)	
African American	-2.584 (0.009)	-2.830 (0.003)	-0.004 (0.917)	-	-1.082 (0.045)	-1.650 (0.006)	-0.400 (0.008)	-0.073 (0.853)	0.532 (0.380)	-
Other	1.132 (0.595)	1.0 (ref)	0.143 (0.090)	-	-0.557 (0.122)	-	0.097 (0.513)	1.0 (ref)	2.119 (0.010)	-
Education, in years, centered at 12 years	0.864 ($<.0001$)	0.874 ($<.0001$)	0.006 (0.217)	-	-0.392 ($<.0001$)	-0.482 ($<.0001$)	-0.021 (0.041)	-	0.477 ($<.0001$)	0.510 ($<.0001$)
Work status										
Full time	1.0 (ref)	-	1.0 (ref)	1.0 (ref)	1.0 (ref)	-	1.0 (ref)	-	1.0 (ref)	-
Part time	0.781 (0.493)	-	0.073 (0.106)	0.094 (0.019)	0.599 (0.339)	-	0.0169 (0.921)	-	0.533 (0.440)	-
Other	0.239 (0.815)	-	-0.038 (0.352)	-	0.869 (0.122)	-	0.018 (0.597)	-	-0.858 (0.166)	-
Body mass index (kg/m ²)	-0.112 (0.081)	-0.122 (0.054)	-0.011 ($<.0001$)	-0.012 ($<.0001$)	-0.141 ($<.0001$)	-0.126 (0.0003)	-0.005 (0.559)	-	-0.047 (0.225)	-
EF*age	-	-	-	0.010 (0.008)	-	-	-	-0.022 (0.065)	-	0.112 (0.056)
Female*age	-	-	-	-	-	0.169 (0.032)	-	-	-	-
Education*AA	-	-	-	-	-	0.271 (0.039)	-	-	-	-
Female*AA	-	-	-	-	-	-	-	-0.476 (0.029)	-	-

	HEI score β Coefficient (p-value)		Yale Activity Index score β Coefficient (p-value)		Cigarettes per day β Coefficient (p-value)		Average drinks on drinking days β Coefficient (p-value)		Overall health behavior score⁺⁺⁺ β Coefficient (p-value)	
Adjusted R ²	0.117	0.121	0.087	0.092	0.082	0.089	0.093	0.102	0.093	0.092
N	918	920	921	921	918	920	918	923	917	921

Variables were included in the final model if they were independently associated with the health behavior outcome, if they were theoretically relevant, or if the addition of the variable substantially changed the relationship between EF and behavior score. Variables with nonsignificant coefficients were removed from each model for parsimony.

Figure 1. Study population



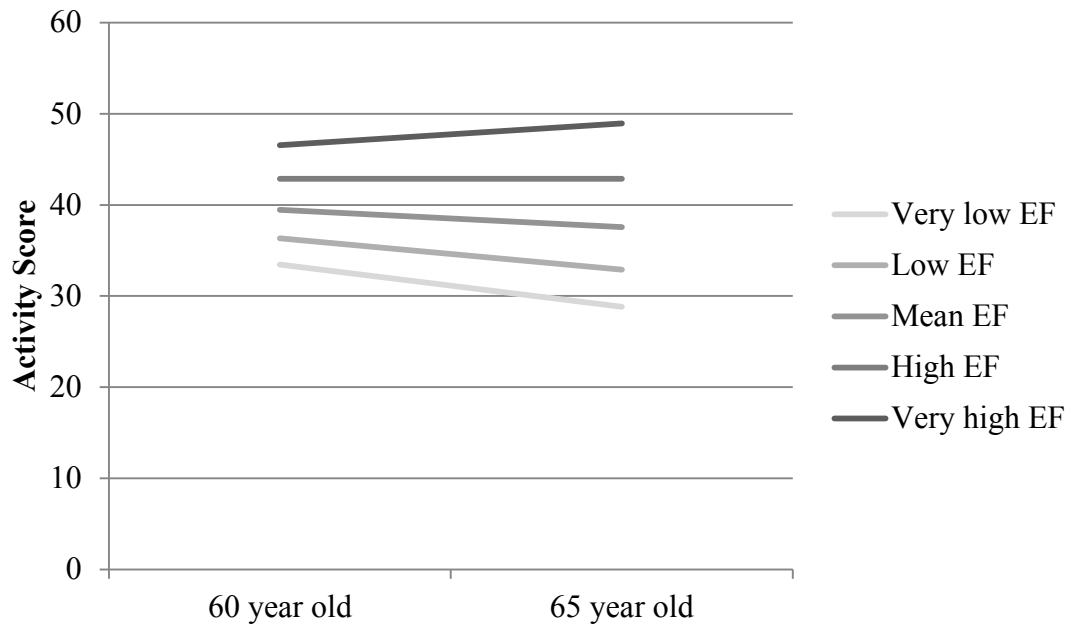
*Defined as scoring 1.5 standard deviations or more from the population mean of both the Trail Making test and the Stroop test, based on a similar protocol used by the study administrators.

**Defined as scoring 2 standard deviations or more below the population EF mean

†9 reported daily calories greater than 5000 and 8 who reported fewer than 500 daily calories

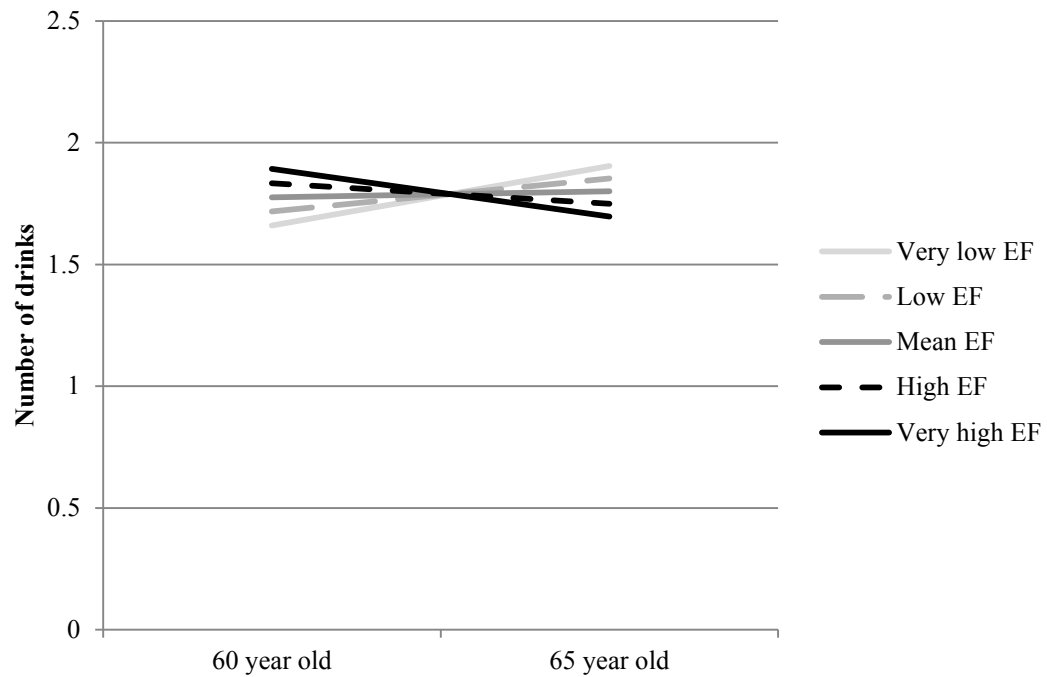
‡Defined as indicating the need for help or being unable to complete more than one activity of daily living (bathing, dressing, eating, walking across a small room, grooming, transferring from chair to a bed, using the toilet)

Figure 2. Predicted Yale Physical Activity Survey activity score by age and executive function score



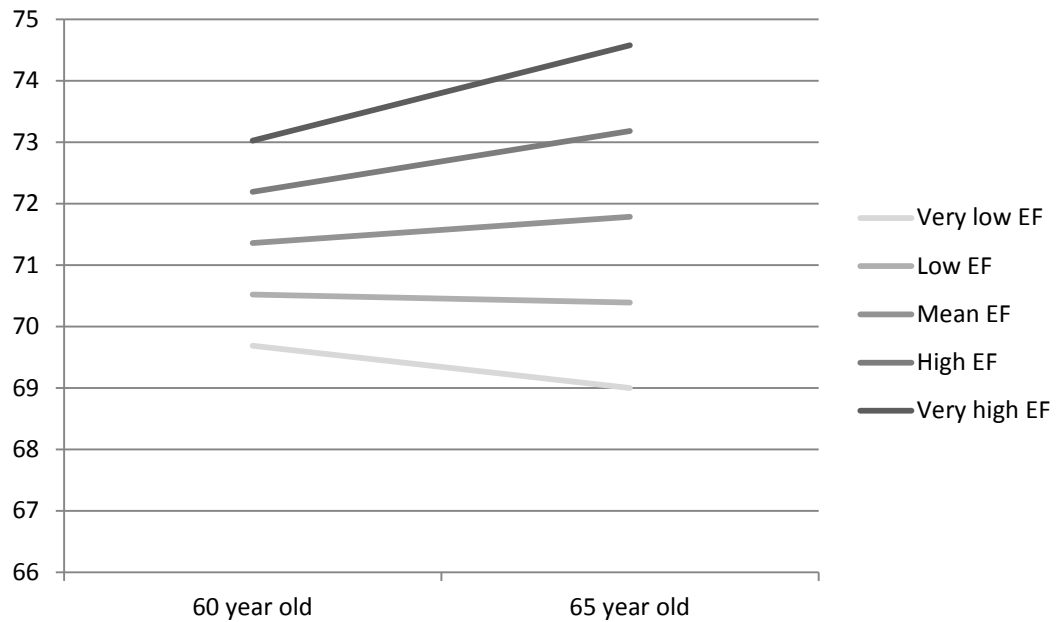
*Values provided are those for women who have a full-time or “other” work status with a BMI of 29.7 (the sample average). Executive function categories are as follows: Very high = EF score of 2, High EF = EF score of 1, Mean EF = EF score of 0, Low EF = EF score of -1, Very low EF = EF score of -2.

Figure 3. Predicted number of drinks consumed on typical drinking day by age and executive function score



*Values provided are those for married men of white or “other” race. Executive function categories are as follows: Very high = EF score of 2, High EF = EF score of 1, Mean EF = EF score of 0, Low EF = EF score of -1, Very low EF = EF score of -2.

Figure 4. Predicted overall health behavior score by age and executive function score



*Values provided are those for men with 12 years of education. Executive function categories are as follows: Very high = EF score of 2, High EF = EF score of 1, Mean EF = EF score of 0, Low EF = EF score of -1, Very low EF = EF score of -2.

CHAPTER 4: REVIEW OF EXECUTIVE FUNCTION IN HEALTH BEHAVIOR RESEARCH

Abstract

Background: A growing field of public health research aims to understand and harness the complex cognitive processes involved in health behavior as individuals navigate their physical and social environments. In particular, executive function (EF) has been the focus of recent attention for its associations with the self-regulatory abilities required for healthy behavior.

Purpose: The aims of this literature review are 1) to summarize collective findings to date on the role of EF in specific health behaviors; 2) to assess how health behavior researchers measure EF, and 3) to identify the theoretical underpinnings of the methods used to study the EF/health behavior relationship.

Methods: A literature review was conducted in PubMed, Academic Search Complete, and PsycINFO to identify empirical articles published between 1994 and 2014 about executive functioning and health behavior. Criteria for inclusion in review were the use of health behavior as the dependent variable and the use of EF as an independent variable in research conducted in human adult populations without conditions or diagnoses known to affect EF. The literature search identified 852 articles that matched inclusion criteria. After applying exclusion criteria and reviewing the reference lists of all candidate articles, a total of 36 articles remained for analysis.

Results: The results of this literature review suggest generally positive findings between the EF/health behavior relationship and point to many varied roles for the effect of EF on health behavior, many ways of measuring EF and health behavior, and many theoretical explanations for the relationship.

Conclusion: As this field of study grows, researchers are encouraged to pay particular attention to the theoretical explanation for the relationship between EF and health behavior, as well as the measurement of EF and the time relationships between the measurement of EF and health behavior.

Introduction

Chronic disease currently accounts for seven of 10 deaths in the United States (Kung, Hoyert, Xu, & Murphy, 2008), shifting the infectious disease prevention goals of the previous era of public health to preventing the avoidable mortality of chronic disease by addressing the behaviors necessary to prevent and treat these diseases. Health behaviors are acknowledged to be difficult to change and maintain, and public health models have evolved to better conceptualize this complexity, moving from individual models to more ecological models that acknowledge the numerous influences on health behavior, including physical environment, social norms, and cultural influences.

At the same time, a growing field of research in public health aims to understand and harness the cognitive processes involved in health behavior as individuals navigate the physical and social environments of their daily lives. In particular, EF (EF) has been the focus of recent attention in public health research (Dunn, 2010; Williams & Thayer, 2009).

Executive function is a neuropsychological construct representing the “higher order” cognitive abilities associated with making decisions, forming goals, planning, organizing, devising strategies for attaining goals, and when necessary, revising those plans (Coolidge & Wynn, 2001).

EF is a relatively new neuropsychological construct, tracing its roots from the “central executive” described by Baddeley and Hitch (1974), along with Luria’s frontal lobe research (1973) and defined further by Lezak (1983) to describe how behavior is expressed and carried out. This term likens executive functioning to the actions of a corporate executive overseeing business operations who takes in information from other sources, makes decisions, and directs attentional and other resources to implement the

actions necessary to meet company goals and priorities. Neuroimaging studies have identified that these abilities emanate from the brain's prefrontal cortex (PFC), which has greater access to the other regions and functions of the brain than any other brain structure. The PFC receives input from all sensory modalities and the outside world to react to stimuli (Suchy, 2009). In contrast to the brain's more automatic reactions (such as the "fight or flight" response), the role of the PFC is essentially to interrupt and "stretch out" time between a stimulus and response (Tucker, Derryberry, & Luu, 2000). This allows higher-order thinking to compare and discard many possible plans or strategies in favor of what is likely to be the most beneficial in the long run, that is, "to be reflective rather than impulsive" (Lewis & Todd, 2007, p. 410).

Research from patients with prefrontal damage has contributed substantially to the understanding and conceptualization of EF. Luria (1966) contributed to this understanding by studying the abilities of individuals with damage to the prefrontal region. These patients are often otherwise healthy with speech and motor function and relatively normal IQ levels but display a lack of flexibility and the ability to grasp, attend to, and process new information. They are unable to conduct goal-directed actions and cannot evaluate success or failure of their behaviors. Such individuals are often stimulus-driven, eating anytime they see food and kicking when they see a ball, regardless of whether these actions are appropriate. One of the first and now-classic descriptions of EF deficits is that of Phineas Gage, a railroad foreman who suffered an injury in 1835 when a tamping rod penetrated his skull and damaged his frontal lobes. He survived the accident in good health but was afterward a dramatically different man with a "childish" and irresponsible personality, making plans then quickly abandoning them, becoming

irreverent and capricious. He was so unlike his former self that his loved ones said of him that he was “no longer Gage.”

Through these and other studies, EF has come to be understood as the abilities that allow us to shift our mindset quickly and adapt to diverse situations while at the same time inhibiting inappropriate behaviors. They enable us to create a plan, initiate its execution, and persevere on the task at hand until its completion (Jurado & Rosselli, 2007).

EF stands in contrast to the brain’s more “automatic” processes, which are performed without intentional direction. Automatic processes are learned and develop over time in response to stimuli and circumstances. Actions, processing schemes, and routines become associated with stimuli, and eventually they become linked with each other so that a cascade of action occurs when a stimulus is encountered (Hughes, 2005). For example, seeing that one’s shoelaces have come untied will likely trigger an automatic response of bending down and retying them without considering or thoughtfully directing every intermediate step. Thus, it is important to recognize that a response that is automatic, habitual or routine is not a reflection of EF (Suchy, 2009). Hughes (2005) suggests that EF differs from automatic processes in that it 1) is the execution of novel vs. routine action sequences, 2) involves the choice of alternative responses vs. a single action sequence (e.g., the shoe tying example above), and 3) is the execution of actions that require access to consciousness. In fact, one aspect of EF is the ability to override a habitual reaction (termed “prepotent response” in the neuropsychology literature) when necessary. Suchy (2009) explains that EF is a highly effortful and, from an energy consumption standpoint, a costly process and is generally

used only when needed, such as during novel or complex situations that require more than an automatic or routine response.

Friedman and Miyake (2012) explain that individual differences in EF among a particular population are largely attributable to genetics but note that the genetic component addresses variability across individuals at one point in time only and not EF “trainability,” which has been suggested by some researchers (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008). This also does not address the state-like features of the cognitive underpinnings of self-regulatory abilities. High-order thinking is costly in terms of energy requirements; research findings by Gailliot et al. (2007) reported that an act of self-regulation actually requires more blood glucose than do other mental acts. Based on their research, Baumeister, Heatherton, and Tice (1994) introduced the self-regulatory strength model, which proposes that the ability to self-regulate is an effortful act and requires a resource that is limited. Self-regulatory strength refers to “the internal resources available to inhibit, override, or alter responses that may arise as a result of physiological processes, habit, learning, or the press of the situation” (Schmeichel & Baumeister, 2004, p. 86). This strength is considered as a resource meant to be expended but limited in quantity. When this resource is depleted, failures in attempts to self-regulate are more likely to occur. This resource can be depleted by emotion regulation, impulse control, making active choices, switching tasks, and solving complex problems (Schmeichel & Baumeister, 2004). This model suggests that the self-regulation resource works like a muscular strength, which is depleted as muscles are used and which is restored only after rest. These authors suggest that similarly to muscle strength, people

seek to conserve self-regulation once it begins to be depleted; they also suggest that self-regulation can be gradually increased by exercise (Schmeichel & Baumeister, 2004).

Though the neuropsychology field generally agrees on the importance, complexity, and general nature of EF, there is much variation in the conceptualization of it. Two main explanations exist: the “theory of unity,” which suggests a singular underlying ability that explain all components of EF (Barkley, 1997; de Frias, Dixon, & Strauss, 2006; Duncan, Emslie, Williams, Johnson, & Freer, 1996; Kimberg, D’Esposito, & Farah, 1997; Parkin & Java, 1999), and one of “non-unity,” which posits that EF can be divided into several components that are distinct parts of an overall construct (Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999; Lehto, 1996; Miyake et al., 2000; Salthouse, Atkinson, & Berish, 2003).

Miyake and Friedman (2000) suggest that EF likely has both a unitary and non-unitary component. They point to three related, but distinct constructs that have become the most widely reported EF factors: response inhibition (the ability to attend to a goal and to inhibit a habitual response in favor of a less used but more appropriate response), updating or working memory (the ability to monitor and hold and manipulate information in short-term memory), and set shifting (the ability to switch between tasks). Despite identifying diversity in these distinct parts, these authors also suggest commonality among all components that is most likely lies in a basic inhibitory and working memory mechanism.

Having such variation in definition makes the measurement of the EF construct very difficult, and many approaches exist. There is no single global test for EF, so neuropsychologists rely on tests that are known to tap frontal lobe functions. Experts

have enumerated several criticisms of using such tests for measuring EF. One of the most pronounced criticisms is that these tasks were designed to be sensitive to impairment in frontal patients. Suchy (2009) points out that this often means that test scores are rarely normally distributed within normal populations and that most healthy individuals can perform the task nearly perfectly, resulting in little variation in test scores.

Suchy (2009) and Jurado and Rosselli (2007) also point out that by definition, EF is an ability called upon in situations of novelty, whereas EF measurement tasks are often very structured, with the test administrator essentially becoming the central executive by providing direction instead of challenging the individual's ability to react to a novel stimulus. Additionally, the networked nature of the PFC means that EF tasks are essentially measuring many areas of the brain. To truly isolate EF, one would need to be able to identify and remove all the other abilities used in the task. Finally, researchers admit that EF tests lack ecological validity; it is rather unclear how well test performance may manifest in everyday life.

Despite the dispute on the exact conceptualization and measurement of EF, neuropsychology seems to agree about the important role that EF plays in daily life, suggesting that it is “the heart of all socially useful, personally enhancing, constructive and creative abilities” (Muriel D. Lezak, 1982). It is particularly associated with several psychological constructs related to health behavior and behavior change: self-regulation (Miyake & Friedman, 2012), emotional regulation, delayed gratification, attentional control, and self-monitoring (Williams & Thayer, 2009). Suchy (2009) suggests that EF is what frees humans from “over-practiced, over-learned, and prepotent responses” as

well as “innate, hard-wired drives and reflexes” by allowing them to consider options, apply lessons learned from past situations, and make decisions toward long-term goals. Given that these constructs are needed to maintain health behavior, it is not surprising that Williams and Thayer (2009) prioritize gaining more understanding about EF of in the maintenance of health behavior and avoidance of risk behavior as an important research goal.

EF has become a focus of recent attention in public health and health psychology research (Dunn, 2010; Williams & Thayer, 2009). EF has been implicated in the addiction literature for some time, but its growth in public health research is likely attributable to Hall, Elias, and Crossley publishing a paper in 2006 that examined the predictive power of EF on health protective and health risk behaviors. The following year, Hall and Fong (2007) published an article on Temporal Self-Regulation Theory, an explanatory model of health behavior that includes “brain-based control resources” and cited EF as the biological basis for self-regulatory abilities that are implicated in health behavior.

In the years since, a growing number of papers studying the role of EF on health behavior have been published, primarily in health psychology, but no known review of this literature has been conducted. Such a review could serve the field well in summarizing the findings and examining the current methods to establish some baseline findings and to provide direction for future research on EF and health behavior. Thus, the aims of this literature review are 1) to assess how health behavior researchers measure EF; 2) to identify the theoretical underpinnings of the methods used to study the

EF/health behavior relationship; and 3) to summarize collective findings to date on the role of EF in specific health behaviors.

Methods

Search Strategy and Data Sources

A literature search was conducted in PubMed, Academic Search Complete, and PsycINFO to identify empirical articles about executive functioning and health behavior. We searched for studies published between 1994 and 2014 using the following search queries: (executive function OR executive control OR executive abilit*) AND (health behavior* OR exercise* OR diet OR physical activit* OR smok* OR cigarette* OR tobacco OR alcohol OR drink*). All search results were limited to those written in English and published in peer-reviewed journals. We also reviewed the references of each article identified for inclusion in the review.

Criteria for Inclusion in Review

The initial search described above resulted in 1416 articles. Criteria for inclusion in review were 1) including executive function in the title or abstract; 2) including a health behavior in the title or abstract; and 3) research conducted in human adult populations.

After we removed articles that did not meet the inclusion criteria, 1039 articles remained (810 from PsycINFO/Academic Search Complete and 229 from PubMed). We then merged the searches from the two databases and identified and removed 187 duplicate articles.

The resulting list included 852 articles. Because we were interested exclusively in the effect of EF on health behavior, we reviewed article titles (and abstracts, as

necessary) to exclude articles for the following reasons: 1) EF was considered to be the dependent variable (e.g., the effects of physical activity on EF) and 2) the article was not empirical (e.g., a literature review), 3) the population of interest had a condition or diagnosis known to affect EF (e.g, schizophrenia), 4) the article focused on a health condition (e.g., obesity) rather than a health behavior (e.g., dietary intake) as the dependent variable, 5) the article was not related to health (e.g., the functions of a corporate executive).

This review removed 789 articles, leaving 24 remaining articles. The references of the remaining articles were examined for additional articles. This added 12 articles. Data from these final 36 articles were indexed in a spreadsheet for analysis. A diagram of the literature review process is presented in Figure 1.

Results

Study Characteristics

Thirty-six articles were included in this study. University students was the most frequently studied population; 17 of the 36 articles studied this population. One article studied first-year medical students. Four articles studied older adults, three articles studied adults in general, and two studied young adults. Seven articles studied drinkers (five studied social drinkers, and two articles studied heavy drinkers). Two articles studied smokers in tobacco treatment programs.

Articles were published in 29 different journals, predominantly in the aging, addiction, and psychology literature. Twenty-nine of the 36 articles were published after 2006. The upsurge may be attributable to Hall and Fong's (2007) article on Temporal Self-Regulation Theory that pointed to EF as the biological basis for self-regulatory

abilities. Of the 29 articles published after 2006, 14 cited one of Hall's articles (four of these articles were published by Hall and co-authors).

Use of Executive Function Measures

Combined, the articles in the sample used 45 different measures to assess EF. Thirteen articles used only one EF measure; eight articles used two measures, seven articles used three measures, and eight articles used four or more measures. Authors used the Go/No-Go task (n=14) and Stroop task (n=12) most frequently, followed by tower tasks (n=8), Trail Making test (n=7), and Wisconsin Card Sorting task (n=5). Table 1 organizes articles by the EF components they measured. The sections below summarize the findings by sub-component according to the way that the authors conceptualized the EF measures they used.

The most-cited conceptualization of EF components is into three sub-components: response inhibition (RI), working memory (WM), and set shifting (SS), but this section uses the categories that authors used in their EF measure descriptions. In the case that authors did not identify which aspect of EF was being measured, we provided the classification according to neuropsychological references.

Response Inhibition

Response inhibition was the most measured EF component, with 24 of the 36 articles including measure of it in their analysis; in 10 of these studies, inhibitory control was the only EF measure used.

The most frequently used measures of RI were the Go/No-Go task (GNG) (n=14) and the Stroop task (n=12), though there were many different ways of measuring performance on these tasks. For GNG, some researchers used mean accuracy, and others

calculated the number of commission errors, reaction time, or a calculated performance index. To create Stroop task variables, researchers used number of errors, difference in response time between the incongruent trials and the congruent trials, or the percentage correct on the incongruent trials.

Two main theoretical considerations provided the underpinning for many of the articles. One group of articles (Allan, Johnston, & Campbell, 2010, 2011; Allom & Mullan, 2012; Booker & Mullan, 2013; Hall, Fong, & Epp, 2014; Hall, Zehr, Ng, & Zanna, 2012; Hall, Fong, Epp, & Elias, 2008; Kor & Mullan, 2011; Mullan, Wong, Allom, & Pack, 2011; Wong & Mullan, 2009), primarily in the physical activity and dietary intake literature, focused on EF as moderating the intention-health behavior gap and specifically theorized that the ability to inhibit prepotent responses allows individuals to resist distractions and temptations to their intended behavior. Another group of articles (Christiansen, Cole, & Field, 2012; Fernie, Cole, Goudie, & Field, 2010; Hofmann, Friese, & Roefs, 2009; Houben & Wiers, 2009; Patrick, Blair, & Maggs, 2008; Sharbanee, Stritzke, Jamalludin, & Wiers, 2014; Sheffer et al., 2012; Wiers, Beckers, Houben, & Hofmann, 2009), primarily in the alcohol and substance use literature, used a dual process approach, suggesting that RI contributes to an individual's ability to regulate associative processes.

Working Memory

Working memory measures were used in seven studies, primarily within the alcohol, tobacco, substance use and adherence articles. To measure WM, five articles used span tasks, and two used the Wisconsin Card Sorting test. Other measures included

the California Verbal Learning test, an n-back task, and the Behavioral Dyscontrol Scale (Brega, 2008).

Several authors (Hofmann et al., 2009; Patrick et al., 2008; Whitney, Hinson, & Jameson, 2006) using a dual process approach theorized that WM is associated with impulsivity. Insel theorized that WM would help older adults remember to adhere to medication guidelines. Other authors (Brega, Grigsby, Kookan, Hamman, & Baxter, 2008; Hoaken, Assaad, & Pihl, 1998; Sharbanee et al., 2014) considered the measures they used as general measure of EF.

Set Shifting

Five articles included tasks measuring set-shifting ability. Four studies (Allan et al., 2011; Tahaney, Kantner, & Palfai, 2014; Wettstein, Wahl, & Diehl, 2014; Whitney et al., 2006) used the Trail Making test to measure this ability, one using the completion time from both the Trails A and B tests and three using only the completion time for the Trails B test. Other measures included the dual task, the Wisconsin Card Sorting task, and a general switching task (McAuley et al., 2011).

Planning

Six articles used neuropsychological tests to tap the planning aspect of EF. All tasks were tower tasks: three used the Tower of Hanoi (measured as time spent preplanning in one study and time spent in preplanning and the number of errors in three other studies), one used the Tower of London task (measured by problem-solving time), and two used the tower task of the Delis-Kaplan EF system (with scoring based on the number of moves required to solve each trial).

All articles containing a measure of planning were related to consumption behaviors (e.g., chocolate, fruit and vegetable consumption, alcohol) and to the intention-behavior gap, with authors positing that the ability to plan could moderate one's ability to realize intentions.

Decision-Making/Risk-Taking

Five articles measured EF constructs related to decision-making or risk-taking. Two used the Iowa Gambling task to do so, two used the Balloon Analogue Risk task, and one used a delay discounting task. Four of the five articles studied smoking or alcohol consumption (the other studied physical activity and dietary intake but did not find an association with decision making). Authors generally considered these measures to be applicable to health behavior in that they are related to impulsivity, which is related to addictive substances and lowered behavioral constraint.

Flexibility

Four articles measured flexibility as an aspect of EF. To measure flexibility, two used the verbal fluency task from the Delis-Kaplan EF system, one used the Iowa Gambling task, and one used the Wisconsin Card Sorting task. All articles measuring flexibility focused on intentions and health behavior and pointed to the importance of flexibility in being able to alter behavior in changing circumstances to attain goal achievement.

Composite Executive Function Measures

Five studies used a composite measure representing multiple facets of EF, either an existing instrument, or a derived composite score from several neuropsychological tests. Two articles existing multi-faceted instruments: one used the Executive Interview,

25 Items (EXIT25), and another used both the Frontal Systems Behavior Scale and the Microcog™ Assessment of Cognitive Functioning. Three articles created composite scores from other EF tests: Deckel et al. (1999) created a measure from the categories (measuring abstraction ability), trail making test (measuring set shifting), and similarities (measuring concrete, functional, and abstract concept formation) tests of the Halstead-Reitan Battery. Giancola (2004) and Godlaski et al. (2009) created a composite measure including the Go/No-Go task, Stroop task (both measuring response inhibition), Porteus Mazes (measuring planning ability), Trail Making test B (measuring set-shifting ability), Wisconsin Card Sorting test, and Tower of Hanoi (measuring planning ability).

Self-Assessments

Four studies used self-assessments to quantify EF. Rather than asking participants to perform tasks designed to measure executive abilities, these instruments ask respondents to self-report their behavior or reactions to real-life situations. Three studies used the Dysexecutive Questionnaire, a 20-item questionnaire of statements concerning everyday life problems (“I act without thinking, doing the first thing that comes to mind”) that participants are asked to rate on a five-point Likert scale in terms of frequency (from “never” to “very often”). One study used the Behavior Rating Inventory of Executive Function—Adult Version, an instrument that contains 75 questions designed to assess executive ability in everyday situations.

Other

Christiansen et al. (2012) used the Controlled Oral Word Association test to measure the phonemic fluency aspect of EF.

Temporal Window of Executive Function/Health Behavior Relationship

Authors used a variety of designs to study the relationship between EF and health behavior, creating varying timespans between the measurement of EF and the measurement of health behavior. The sections that follow describe the study designs and the temporal windows created by these designs, from the smallest temporal window to the largest. Figure 2 illustrates the temporal windows of each design.

Monitoring Studies

Three articles measured adherence to a defined health behavior standard. Two studies measured EF and then monitored the health behavior of interest for a varying amount of time. Insel et al. (2006) measured EF and then monitored medication adherence in older adults for eight weeks using a medication monitoring device. McAuley et al. (2011) measured EF and then monitored older adults' participation in a 12-month exercise program. Wettstein et al. (2014) measured EF and monitored out-of-home behaviors in older adults using a GPS tracking device for up to four weeks.

Follow-Up Studies

Thirteen articles measured participant EF and then measured health behavior in a later visit. Ten of these studies were specifically measuring the relationship between EF and intentions toward the respective health behavior. To do so, they measured EF and health-related intention at time 1; all but one measured the self-reported health behavior one week later (the exception measured health behavior 3 days later). Three other studies incorporated longer time intervals. Two studies about smoking cessation measured participant EF and then used multiple follow-up visits to measure cessation success – one up to eight weeks, the other up to 28 weeks. Deckel et al. (1999) measured EF and

alcohol consumption and then followed with another alcohol consumption measurement three years later to measure overall change in drinking behavior.

Laboratory-Based Studies

Eight articles studied the relationship between EF and health behavior in a lab-based setting. Six articles were about alcohol consumption or alcohol-related aggression; two were about candy consumption.

Five articles used an experimental design. Four alcohol-related aggression articles used a similar design in randomizing individuals into groups that consumed alcohol or a placebo beverage. Both groups were then given an aggressivity test, and results were compared. One alcohol consumption study randomized individuals to either an ego-depleting task or a control task and measured ad-lib drinking to investigate whether ego-depletion is a mediator of the EF-drinking relationship.

Three studies used a lab-based observational approach to study candy consumption and an alcohol-related anticipation of effect measure, respectively. After measuring EF, these studies asked participants to test and rate a product. For the candy consumption studies, the amount of candy consumed was the outcome measure. For the alcohol study, an anticipated effect of alcohol measure was the outcome.

Questionnaire Studies

Eleven articles measured health behavior using self-report questionnaires, asking participants about current or past health behavior at the same time that EF was measured. Two articles asked participants about current behavior. Six articles asked participants about past behavior (two asked about behavior in the past week, one each about the past month, past four months, and six months, respectively) and one asked about the past three

years. Three articles asked about both past and current behavior: all three of these concerned past and current smoking.

Health Behaviors Studied and Study Findings

Health behaviors studied included alcohol consumption (n=8) and alcohol aggression (n=5), dietary intake (n=6), physical activity (n=3), smoking (n=3), medication adherence (n=1), and sleep (n=1). Eight articles featured more than one health behavior. Table 2 describes the studies for each type of health behavior, and the sections below summarize findings for each health behavior.

Physical Activity

Four articles studied the relationship between EF and physical activity. Two of these articles looked specifically at intention and physical activity. Hall et al's (2008) fMRI investigation reported more effective engagement of executive attentional and inhibitory networks in university students who showed higher self-regulation in meeting their exercise intentions over the course of a week than did the "unsuccessful self-regulators." These authors also reported intention to be a more substantial predictor of physical activity in participants with a high RI score, suggesting that those with higher EF abilities were more likely to realize their health intentions. These authors also reported that intention was a more substantial predictor of physical activity in university students with a high EF score. They also reported that EF predicted unique variance above intention alone. Hall et al. (2012) looked at the influences of RI, intention strength, and implementation intention ("if-then" plans that specify where and when an action will occur) on physical activity in supportive and unsupportive environments (i.e., summer and winter seasons, respectively). These researchers found that in supportive conditions,

RI moderated the intention-behavior relationship, regardless of implementation intention. In unsupportive conditions, however, implementation intention eliminated the deleterious effect of low EF on the intention-behavior relationship.

McAuley et al. (2011) investigated whether EF would predict adherence to an exercise program among older adults. The authors reported that some EF measures (the Stroop task and dual task) but not others (Wisconsin Card Sorting test, flanker task, and task switching) were mediated by self-efficacy in affecting higher levels of exercise. The authors suggest that these results are supportive of the idea that EF is implicated in physical activity, but that the relationship is indirect.

Hall, Elias, and Epp (2006) reported that RI was not associated with exercise frequency in a sample of adults after controlling for age, gender, and years of education.

Dietary Intake

Seven articles were identified as examining some aspect of EF and dietary intake. Four articles studied EF-related aspects of unhealthy dietary intake. Allan et al. (2010) reported RI, but not planning ability, was associated with chocolate consumption among those who intended to avoid high-calorie sweets. Allan et al. (2008) found that a task switching measure, an overall measure of self-report executive control, and a Stroop task score but not a GNG score (both of which measure RI) contributed significantly in the high-calorie snacking intention-behavior gap. Hall et al. (2012) reported that RI (measured by Stroop task and GNG tasks) was associated with consumption of fatty foods (but not non-fatty foods). Hofmann et al. (2009) reported that executive attention and RI each moderated the relationship between automatic affective reactions and candy consumption, also reporting that these two factors were themselves uncorrelated and that

they moderated the affective reaction-consumption relationship separately, suggesting multiple pathways to impulse control.

Three articles considered the association of EF with healthy dietary intake. Allom and Mullan (2012) reported that RI, but not planning, was a moderator of the relationship between intention and consumption of fruits and vegetables, but only among those who identify with being a healthy eater. Those who did not identify with health eating were more likely to eat more fruits and vegetables if they had previously formed a strong habit. Hall, Fong, Epp, and Elias (2008) reported that intention was a more substantial predictor of fruit and vegetable consumption in university students with a high EF score. They also reported that EF predicted unique variance above intention alone.

Allan et al (2011) found that a task switching measure of EF and overall executive control measure, and one measure of RI (Stroop task) but not another (GNG), contributed significantly in explaining variance of the fruit and vegetable intention-behavior gap.

Wong and Mullan (2009) found that planning ability explained unique variance in behavior and moderated the intention-behavior relationship for low-intention but not high-intention participants (those with high intention strength showed a positive association with breakfast consumption regardless of planning ability). The authors did not find RI to explain any additional variance in breakfast consumption.

Smoking

Seven articles looked exclusively at EF and smoking. Brega et al. (2008) reported that Behavior Dyscontrol Scale (BDS) score (described as mainly a measure of executive impairment) somewhat predicted whether an individual had stopped smoking, but it did not predict whether a person had ever smoked, the age at which they started smoking, the

age at which they stopped smoking, or the number of cigarettes smoked per day among older adults. Sheffer et al. (2012) found that three different measures of delay discounting and one measure of cognitive impulsiveness (the Barratt Impulsiveness Scale 11) predicted smoking cessation among low SES participants enrolled in intensive cognitive-behavioral treatment for tobacco dependence. Several other EF measures, however, including the GNG task, the MicrocogTM Assessment of Cognitive Functioning, Frontal Systems Behavior Scale, and a different measure of impulsiveness (the Eysenck Impulsiveness Scale) were not statistically significant predictors of abstinence.

Hall, Elias and Crossley (2006) reported that after controlling for age, gender, IQ, and number of years of formal education, RI (using Stroop test errors) was a statistically significant predictor (and stronger than a measure of IQ) of number of pack years smoked.

Menon et al. (2013) reported that EF (as measured by the EXIT25) was associated with smoking status after controlling for demographic variables in a population of English-speaking Hispanic and non-Hispanic White older adults. EF also fully mediated the relationship between a measure of education quality and smoking.

Three articles found no statistically significant association between EF and smoking. Schlam et al. (2011) investigated whether several types of performance on a modified Simon task (an index of executive control function during exposure to affective, neutral, and smoking images) would predict abstinence in smokers following a quit attempt. The authors reported that neither “sticky attention” nor EF impairment predicted cessation outcomes, though the authors did report differences in response to appetitive stimuli vs. negative stimuli between successful vs. unsuccessful abstainers, suggesting

that unsuccessful abstainers may find environmental appetitive cues especially distracting and persistent in their working memory resources and may induce cravings.

Black et al. (2011) examined the intercorrelations between mindfulness, self-control, and working memory (as measured by an automated operation span task) and their association with smoking among first-year medical students. Working memory was not statistically significantly correlated with smoking. Magar et al. (2008) reported that EF (as measured by the Dysexecutive Questionnaire) was not a predictor of age of first cigarette in a population of undergraduates.

Alcohol Consumption

Thirteen articles examined the role of EF and alcohol consumption. Deckel et al. (1996) reported that a composite measure of EF was a marginally statistically significant predictor of drinking problems three years later and was a moderator of the family history/future alcohol consumption relationship. Mullan et al. (2011) reported that the main effects of the planning and RI measures did not explain any additional variance in drinking behavior beyond that explained by intention, but both planning and RI did moderate the relationship between intention and binge drinking. Black et al. (2011) examined the intercorrelations between mindfulness, self-control, and working memory (as measured by an automated operation span task) and their association with problem alcohol use among first-year medical students. Working memory was not statistically significantly correlated with harmful alcohol use.

Hall, Elias and Crossley (2006) reported that after controlling for age, gender, IQ, and number of years of formal education, RI (using Stroop test errors) was a statistically significant predictor (and stronger than a measure of IQ) of problems with alcohol.

Menon et al. (2013) reported that EF (as measured by the EXIT25) was associated with problem drinking (in separate models) after controlling for demographic variables in a population of English-speaking Hispanic and non-Hispanic White older adults.

Magar et al. (2008) reported that EF (as measured by the Dysexecutive Questionnaire) was a predictor of alcohol-related problem behaviors in a population of undergraduates. Executive function also predicted placing greater emphasis on the associated benefits and less importance on the potential drawbacks of risky actions.

Whitney et al. (2006) reported that it was not EF deficits that predicted the degree to which university students suffered negative consequences from drinking alcohol but rather a qualitatively different pattern of making quick decisions and maintaining irrelevant information in their working memory, which makes the inhibition of prepotent responses more difficult.

Fernie et al. (2010) reported that a measure of risk-taking, but not RI or delay discounting, was a significant predictor of alcohol use in university students. Christiansen et al. (2012) reported that ego depletion was associated with increased drinking in heavy social drinking university students tested, but no EF measures appeared to mediate the effect of ego depletion on drinking.

Several articles studied EF within the context of the dual process model of alcohol consumption. This model suggests that two cognitive forces are at play in alcohol consumption in heavy drinkers, generally hypothesizing that EF in the form of inhibitory control helps to curb associative processes related to alcohol. Houben and Weirs (2009) reported RI to be a moderator of the alcohol associations/drinking behavior relationship.

These authors suggested that their findings suggest that the ability to inhibit responses determines whether alcohol associations predict drinking behavior.

Tahaney et al. (2014) reported that a Trail Making test score (a measure of set-shifting) moderated the relationship between the urge-to-drink and drinking behavior and the anticipation/drinking relationship among those with high levels but not low levels of drinking self-control goals. Similarly, EF moderated the anticipation/drinking relationship among those with high self-control goals but not low ones.

Sharbanee et al. (2014) reported that the interference suppression aspect of inhibitory control (which happens when a person must maintain abstract information in the face of distracters) inhibited alcohol action tendencies in a sample of university students but that dysregulated drinkers showed similar skill as regulated drinkers in the study's interference suppression tasks, suggesting that difficulty in regulating consumption was not merely a matter of inhibitory deficits.

Patrick et al. (2008) reported that working memory score was a statistically significant moderator of the approach sensitivity/alcohol consumption relationship, in that individuals higher in approach sensitivity and better WM were associated with *more* alcohol use. Additionally, RI was a marginally significant of the approach sensitivity/alcohol consumption relationship, with approach sensitivity associated with higher levels of alcohol consumption only among those with lower RI scores. The researchers also reported that RI, but not WM, moderated the relationship between emotional decision making and alcohol use, with higher levels of alcohol use among those of lower RI and poor emotional decision making, while among those of higher RI, emotional decision making was not associated with alcohol use.

Alcohol-Related Aggression

Five articles examined the effect of EF on aggression related to alcohol consumption. Wiers et al. (2009) reported that RI was a significant moderator of the associations/aggression relationship, indicating a stronger relationship between alcohol power associations and aggressiveness after drinking among those with lower EF. Giancola (2004) reported that a composite measure of EF moderated the alcohol-aggression relationship among men, and Godlaski and Giancola (2009) reported that irritability mediated the EF/intoxicated aggression among men. Hoaken et al. (1998) also reported that EF moderated the alcohol/aggression relationship.

Giancola et al. (2012) reported that the overall BRIEF-A score predicted intoxicated aggression, but that the Behavioral Regulation Index (BRI), a BRIEF-A composite measure that measures inhibition, emotional control, flexible thinking, and self-monitoring, was a better predictor than the overall measure and was also a moderator of the alcohol-aggression relationship. Further analysis considered each of the BRI components, but they were not statistically significant predictors. On the other hand, the other BRIEF-A index, Metacognition Index (MI), a composite measure of initiation, working memory, planning/organization, task monitoring, and materials organization, did not predict alcohol-related aggression.

Medication Adherence

Insel et al. (2006) reported that a composite score of several WM tests was the sole statistically significant predictor of medication adherence among older adults. Neither general cognition nor a general memory composite score was associated with medication adherence, suggesting the unique role of WM rather than overall cognitive ability.

Sleep Hygiene

Response inhibition was the strongest predictor of sleep hygiene in a study by Kor and Mullan (2011), though its statistical significance disappeared when a past behavior variable was added to the regression model. Taken with other findings from the analysis, the authors concluded that sleep habits of university students aren't habitual and therefore require a self-regulatory capacity, of which RI is a component.

Hall, Elias and Crossley (2006) reported that after controlling for age, gender, IQ, and number of years of formal education, RI (using Stroop test errors) was a statistically significant predictor (and stronger than a measure of IQ) of sleep difficulties.

Out-of-Home Behaviors

Wettstein et al. (2014) reported that a Trail Making test measure was a marginally significant predictor of an activity engagement measure of out-of-home behaviors (OOHB). Out-of-home behaviors are defined as a range of behaviors involved in moving from one location to another and participation in activities outside the home; they are cited in the literature as critical for the maintenance of good health in aging populations (Montero-Odasso et al., 2005). The authors measured OOHB using global mobility (total time spent away from home), distance travelled from home, and a measure of walking (distance, speed, frequency, etc.) among cognitively unimpaired community-dwelling older adults. The WM measure was a marginally statistically significant predictor of the mean distance from home measure, with individuals with higher WM scores traveling farther distances from home.

Cancer Screenings

Menon et al. (2013) reported that EF (as measured by the EXIT25) was associated with number of cancer screenings after controlling for demographic variables in a population of English-speaking Hispanic and non-Hispanic White older adults. EF partially mediated the relationship between education quality and number of cancer screenings.

Drug Use

Patrick et al. (2008) reported that WM score was a marginally significant moderator of the approach sensitivity/drug use relationship. Individuals higher in approach sensitivity and better WM were more likely to have *more* drug use.

Black et al. (2011) examined the intercorrelations between mindfulness, self-control, and working memory (as measured by an automated operation span task) and their association with substance use among first-year medical students. Working memory was not statistically significantly correlated with substance use.

Multiple Behavior Measures

Six articles studied the relationship between EF and several health behaviors within the same article but examined each relationship separately. Detailed findings for each health behavior are summarized in the respective sections above, but this section highlights where similarities and differences in the EF/health behavior relationships were identified.

Hall, Elias and Crossley (2006) reported that RI was a statistically significant predictor of number of pack years smoked, problems with alcohol, and sleep difficulties, but not exercise frequency. Hall, Fong, Epp, and Elias (2008) reported that intention was

a more substantial predictor of physical activity and fruit and vegetable consumption participants with a high EF score among university students.

Menon et al. (2013) reported that EF (as measured by the EXIT25) was associated with number of cancer screenings, smoking status, and problem drinking after controlling for demographic variables in a population of English-speaking Hispanic and non-Hispanic White older adults. EF fully mediated the relationship between a measure of education quality and smoking, partially mediated the relationship between education quality and number of cancer screenings, but did not mediate the relationship between education quality and problem drinking.

Patrick et al. (2008) reported that EF scores did not predict alcohol or drug use scores as main effects in a sample of young women, though a higher IGT score was associated with less alcohol consumptions. Working memory score was a statistically significant moderator of the approach sensitivity/alcohol consumption relationship and a marginally significant moderator of the approach sensitivity/drug use relationship.

Black et al. (2011) reported that WM was not statistically significantly correlated with substance use, harmful alcohol use, or smoking among first-year medical students.

Magar et al. (2008) reported that EF (as measured by the Dysexecutive Questionnaire) a predictor of alcohol-related problem behaviors but not age of first cigarette in a population of undergraduates.

Composite Measures

Hall, Fong, and Epp (2014) reported that RI (as measured by GNG and Stroop) predicted nearly twice as much variability in a health behavior composite score (comprised of physical activity and fatty food intake) as did personality traits and

partially explained the association between personality factor and health behavior among an age-stratified sample. The authors also reported that RI had the strongest effect in middle and older adult populations.

Booker and Mullan (2013) reported that planning and RI were associated with better implementation of health behavior intentions in a healthy lifestyle score (including measures of physical activity, fruit and vegetable consumption, breakfast consumption, sleep, alcohol consumption, and smoking). On the other hand, rational decision-making ability (as measured by the Iowa Gambling test) did not predict successful implementation of health behavior intentions. The authors also reported on differences in individuals using EF in various supportive or unsupportive environments. In supportive environments, EF and behavioral prepotency had a bigger influence than did self-regulation or intention. In unsupportive environments, however, both self-regulation and behavioral prepotency were predictive of health behavior.

Discussion

Executive Function Measures

Executive function is a relatively new construct in neuropsychology. While myriad tests exist to measure it, EF researchers are divided in the approach to conceptualizing it. With this general sentiment in the neuropsychology field, there is no particular gold standard from which the health psychology and public health fields can draw for EF measures. The research represented by this literature review reflects a wide variation in approaches to EF measurement. The sheer number of different neuropsychological tests was remarkable, with 45 different tests used.

Papers in this review tended to fall into one of four main approaches for assessing EF and health behavior: 1) measuring more than one aspect of EF and using the measures separately in analytic models; 2) concentrating on measuring only one aspect of EF; 3) using a composite measure comprising various EF tests that measure different aspects of EF; and 4) using self-assessments of EF ability based on everyday life situations. Figure 3 illustrates these approaches graphically.

The most prevalent approach was the use of multiple EF measures, in which authors used more than one test to measure different aspects of EF. Thirteen studies in this review used this approach, and most of these authors included all EF components in the same health behavior model, often including all EF measures in one step of a hierarchical regression analysis rather than testing the measures in separate models. This method suggests a theoretical approach that considers each EF measure contributing separately to a particular health behavior. In support of this approach is the fact that of the articles that reported intercorrelations between EF measures, none reported intercorrelations above 0.37, and many reported that there were no significant correlations between the EF variables, suggesting the uniqueness of the factors.

Authors who used this approach largely theorized that specific aspects of EF were particularly salient for the health behavior in question and hypothesized that different facets of EF would be differentially predictive of health behavior. This was largely found to be true, with most authors reporting different results for the various components – response inhibition, for example, but not working memory, being a significant predictor of health behavior. Most explicitly, Hofmann et al (2009) demonstrated that three different components of EF each moderated the affective reaction/candy consumption

relationship separately, suggesting that each had an influence independent of the others. McAuley et al. (2011) concluded from their study that inhibitory control and multitasking are more important for exercise adherence than is cognitive flexibility.

On the other hand, 12 other papers focused their research on testing only one aspect of EF. Of these 12 papers, 10 of them focused on response inhibition – this may not be surprising, as Miyake and Friedman (2012) suggest response inhibition as a commonality among all components of EF.

Articles that focused on only one EF component had strong theoretical backgrounds and were specific in their research objectives regarding EF components. For example, Hall's work focused specifically on health behavior intentions, so his research used only measures of RI and no others. Sharbanee et al. (2014) specifically studied one aspect of the inhibitory process, explaining that researchers typically use measures that use only one or both aspects of the process, which could explain inconsistent results.

Four studies used a composite measure only in their analysis. All found significant (or marginally significant) relationships with health behavior.

And so, two basic paradigms existed in the research reviewed – one of assessing more general EF ability (or multiple aspects of EF) and another of focusing solely on one component. The findings of Giancola and Godlaski (2012) offer an interesting insight to the matter of EF measurement and health behavior, as they examined multiple levels of measurement. These authors first used the BRIEF-A score, which was a significant moderator of alcohol-induced aggression, but they found that one of the BRIEF-A's sub-component indexes measuring behavioral regulation was a better predictor than the

overall measure. At the very granular level, the authors reported that none of the sub-components of that index was a significant predictor. This seems to underscore the importance of measurement and theoretical understanding in EF research; in that study, only the mid-level of measurement showed the highest predictive value while offering some theoretical specificity.

This leaves researchers to consider the best approach for studying EF in the health behavior context. Taken together, these findings belie the newness of the field and the importance of continuing to progress and build on the existing EF/health behavior literature.

Temporal Window of Executive Function/Health Behavior Relationship

Another key contribution to theoretical understanding in the field is the temporal aspect of the effect of EF on health behavior – specifically understanding the effects of EF on health behavior in the short, medium, and long term. The articles in this study showed considerable variation in the time elapsed between the measurement of EF and health behavior – time ranging from minutes to several years. Most of the literature theorizes that EF affects health behavior through self-regulation, and associations suggest that individuals with higher EF have healthier behavior scores, but no clear conceptualization has been established regarding how EF works to affect health behavior over the course of a lifetime in the real world. Several authors of articles included in this study commented on the correspondence of time elements between EF and health behavior measures and the need to further explore the longer-term effects of EF on health behavior.

Articles in this study seemed to fall into two categories in this regard. The first group, representing more than half of the all the studies reviewed, investigated health behaviors in a time period very close to the measurement of EF. Eight of these studies measured behavior in a lab-based setting, studying how differences in EF correspond to immediately different behaviors. Two questionnaire studies looked at current behavior, and 12 measured behavior one week before or after measuring EF. The second group examined the EF/behavior relationship over a time period of months or years. These studies gathered data on behavior in the past months or years or followed up with behavior in as much as three years after EF was measured.

Inherent in all this research is the assumption that EF is a static ability – that one's EF ability at one measurement point would be the same or similar when health behavior was assessed. While research suggests that individual variation in EF abilities is largely genetic (Friedman & Miyake, 2008), researchers have also described the ability to build EF with training (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008), as well as the phenomenon of depleting EF by taxing it (Baumeister, Heatherton, & Tice, 1994; Schmeichel & Baumeister, 2004). No studies included in this literature considered possible fluctuation in EF when health behavior was measured, even the ones who measured health behavior years later. Researchers who investigate the EF/health behavior temporal relationship may want to consider this in their methodology.

Health Behaviors

Most studies in this literature review reported associations between EF and health behavior, including physical activity, dietary intake, smoking cessation, alcohol consumption, alcohol-related aggression, medication adherence, sleep hygiene, and out-

of-home behaviors. Associations with different aspects of EF, however, were varied and mixed. The most consistent finding was with response inhibition, which may support for Miyake and Friedman's suggestion of it as a common ability underlying EF. That said, there was much inconsistency between findings for individual aspects of EF. Among the studies that considered multiple measures of EF in their models, most reported that only some were associated with health behavior.

Some authors offered explanations for this trend, suggesting that different EF processes may be at work in enacting healthy behavior vs. avoiding unhealthy behavior and suggesting the need for the development of models to address each. Allan et al. (2011) suggest that resisting the temptations of unhealthy behavior is more likely to be more dependent on inhibitory ability while implementing intentions for healthy behavior (e.g., starting a new diet) requires different self-regulatory processes. The dual process model used in many of the alcohol studies aims to provide an explanatory model for impulsive behavior. Creating explanatory models for other types of behaviors is likely an important area of future research.

Many of the articles in this literature review investigated main effects of EF to test the predictive its power for various health behaviors, with the hypothesis that higher EF ability would be associated with healthier behavior. This is a logical beginning point for a new area of research such as EF and health behavior. Several factors, however, point to the need to develop a more nuanced understanding beyond a deficit model, which suggests that lower levels of EF are associated with poorer health behavior.

Notably, rather than reporting positive main effects, many study findings described EF as a moderator of the relationships between other variables and health

behavior. Most of these articles concerned either intention or associative processes. Executive function moderated the relationship between intention and physical activity, consumption of unhealthy snacks and candy, fruit and vegetable consumption, and urge-to-drink, alcohol anticipation effects, and drinking behavior. These studies generally found that those of high EF and high intentions were most likely to have healthier behavior.

The other frequently reported moderation relationship concerned associative processes and alcohol consumption, exclusively used under theoretical guidance of the dual process model, which suggests two cognitive forces at play in alcohol consumption and other health behaviors. This model generally hypothesizes that EF in the form of response inhibition helps to curb the lower-order associative processes (e.g., automatic affective reactions, alcohol associations, approach sensitivity) related to alcohol or other substances. One article (Hofmann et al., 2009) extended this dual process model to candy consumption and reported an association between three EF measures and consumption.

Executive function was also found to moderate the alcohol/aggression relationship, emotional decision making/alcohol consumption relationships, and the alcoholism family history/alcohol consumption relationship.

Several authors suggested that the EF/health behavior relationship may not be a straightforward one. Despite identifying RI as a moderator of alcohol action tendencies and alcohol consumption, Sharbanee et al. (2014) pointed out that dysregulated drinkers showed similar skill as regulated drinkers in the study's RI tasks, suggesting that difficulty in regulating consumption was not merely a matter of inhibitory deficits. Whitney et al. (2006) found qualitatively different patterns in EF abilities to be associated

with impulsive drinking behavior, specifically a pattern of quick decision-making in conjunction with maintaining information in WM that is no longer relevant, which the authors hypothesized may cause trouble in inhibiting prepotent responses. Similarly, Schlam et al. (2011) did not find that EF predicted smoking cessation but did identify a pattern suggesting that individuals with poorer smoking cessation outcomes may be unable to remove appetitive cues from their working memory, causing an increase in cravings. Patrick et al. (2008) reported that higher EF doesn't always result in healthier behavior. These authors found that higher WM ability coupled with high approach sensitivity was associated with more rather than less alcohol and drug use, though higher RI scores and high approach sensitivity and higher RI scores and poor decision making were associated with less drinking.

Several authors using a dual process approach suggested that both the associative and EF processes are crucial for addictive behaviors. Wiers et al. (2009) suggested that it is the coupling of an EF deficit with the relevant associative process that is associated with poorer behavior, explaining that impulsive behavior (such as aggression, unsafe sex, alcohol or drug use) is not merely a matter of low EF abilities, but also an associative process that leads to a particular behavior. Conversely, Sharbanee et al. (2014) suggested that while associative processes can account for motivation to consume alcohol, their research suggested that it alone is insufficient for dysregulated drinking, hypothesizing that such drinking may be the result of an imbalance of associative processes and interference suppression.

While nearly all studies examining a more complex relationship between EF and health behavior were in the addictive substances literature, one study did investigate the

dual process model in relation to candy consumption, suggestive of a potentially broader application for other health behaviors. Hofmann et al. (2009) reported affective reaction was related to candy consumption and that three different components of EF each moderated the relationship.

The studies described in this literature review offer empirical and theoretical evidence of the role that EF has in health behavior. Building on this evidence and developing more explanatory models is a logical next step in the continuation of this research.

Conclusions and Future Directions

The present study reviewed the growing literature about the role of EF on health behavior with the aim to provide a baseline summary of findings for informing theoretical understanding of health behavior and to offer suggestions for future research on EF and health behavior. This area of study has promise to add another meaningful layer to the multi-level understanding of the influences of health behavior. A cognitive view of health behavior can be very helpful in better understanding how people interact with the stimuli in their environments, especially in modern society, which, as Hall et al. (2007) suggest, “largely pulls for unhealthy behaviors as the default” (p. 445). A neuroscientific understanding explains that self-regulation is energy-costly and effortful, and that much of behavior is driven by habits and environmental stimuli.

The research reviewed in this study will become the seminal foundation from which future researchers will build. Based on our review, we highlight several areas for attention that could move the research forward to be maximally useful for affecting the epidemic of chronic disease and the health behaviors associated with it. The goal of this

literature review was to summarize of the current state of the literature and to point out some possible paths ahead for broadening and deepening this area of research. It is hoped that this consideration of findings and gaps can serve this research area well as it works to better understand the cognitive aspects of health behavior.

First is attention toward the theoretical models that underlie the study of EF's association with various health behaviors. Given this research area's nascence, it is understandable that many of the studies in this literature review tested general associations between EF and health behavior, especially in mainstream public health behaviors where this is a novel application of cognitive research. Results from the studies in this review largely showed positive associations between EF and healthy behavior, suggesting that considering the cognitive underpinnings of health behavior may be a helpful theoretical construct for health behavior promotion and interventions for risk behaviors.

The study of EF and its role in alcohol consumption enjoys a longer history than does the study of EF and other health behaviors. This means that findings of EF and alcohol consumption and alcohol-related aggression are more robust and with a more developed theoretical understanding. This body of literature has moved beyond a deficit model understanding of behavior to investigate cognitive patterns that better explain health behavior. Other health behaviors would benefit from a similar treatment. This would likely involve a consideration of each health behavior separately – including a careful consideration of which EF components are implicated – to better understand the cognitive processes involved in each health behavior. As some authors pointed out,

different EFs are likely involved or are used differently in positive health behaviors as opposed to risk behaviors.

Next, we recommend particular attention to the measurement of EF. Articles in this literature review were quite reflective of the variation that exists among neuropsychologists in the conceptualization and measurement of EF, using many different approaches to measure it. There was also much variation in the way that EF measures were considered in models, with some authors using composite measures, others including multiple EF measures in the same model, and others considering each EF measure separately. While there is something to be gained by all this research, it makes comparability of results difficult and also dilutes the understanding of the EF-health behavior relationship, in neither being able to represent the larger EF construct nor being able to speak in depth about one specific component.

Instead, we recommend a more theoretical and explicit consideration. This includes developing and articulating a solid explanation of the EF construct and carefully define all terms and variables (Suchy, 2009), selecting appropriate EF components and EF measures that are associated with the theoretical approach being hypothesized as well as how the use of those specific measures may influence results and the understanding of the EF/health behavior relationships. Many researchers represented EF with only one or two component measures, but didn't necessarily extend the interpretation of results to include only the aspect of EF that was measured. If composite measures are used, researchers should ensure that measures cover a theoretically sound model of EF components. Authors who concentrate on only one aspect of EF should consider Miyake and Friedman's (2000) advice of using multiple measures to ensure against task impurity.

Lastly, the study of the EF/health behavior relationship would benefit from considering the role of time in the measurement of EF and health behavior to gain understanding about how EF affects behavior. The articles in this study generally concentrated on confirming associations between EF and health behavior on a macro level or shedding light on more immediate EF/behavior connections. Both approaches can add to our understanding of EF and health behavior, but they also raise several questions about this relationship. Two main questions seem to emerge: 1) What EF processes underlie the associations observed between EF and health behavior in the wider temporal windows (months, years, the lifespan)? And conversely, 2) can we expect that the associations identified in shorter time frames to be sustained or multiplicative over longer time periods? These questions might frame research objectives in future research in this area. Perhaps results from a third category of studies in this literature review may span the information gap. These studies were more longitudinal in nature, measuring health behavior at several time points, ranging from one week to several years.

Finally, a more difficult, but ultimately helpful direction for future research would also be in studying the ecological validity of EF measures on “real world” health behavior. The ecological validity of EF is a recurring criticism of EF measures, but in the field of public health, it is critical to understand how low or high (or the changing state) EF resources translate into health behavior. This could ultimately inform interventions, prevention, and behavior change efforts.

The results of this literature review suggest generally positive findings between the EF/health behavior relationship and point to many varied roles for the effect of EF on health behavior, many ways of measuring EF and health behavior, and many theoretical

explanations for the relationship. Indeed, this area of study brings with it not only the challenges of burgeoning research but also the challenges of interdisciplinary research with an area of study that suffers from great division even in its theoretical home.

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Table 1. Executive function component measurements

Authors	Response Inhibition	Working Memory	Set Shifting	Planning	Decision Making/ Risk Taking	Flexibility	Overall Measure
Allan, J.L., Marie Johnston, M., & Campbell, N. (2010).	Stroop task			Tower task		Fluency task	
Allan, J.L., Marie Johnston, M., & Campbell, N. (2011).	Go/No Go task Stroop task		Trail Making task	Tower task		Verbal fluency task	Dysexecutive Questionnaire
Allom, V., & Mullan, B. (2012).				Tower of Hanoi	Iowa Gambling task		
Black, D. S., Semple, R. J., Pokhrel, P., & Grenard, J. L. (2011).		Automated open span task					
Booker, L., & Mullan, B. (2013).	Go/No-Go task			Tower of London task	Iowa Gambling task		
Brega, A. G., Grigsby, J., Kookan, R., Hamman, R. F., & Baxter, J. (2008).		Behavioral Dyscontrol Scale					
Christiansen, P., Cole, J. C., & Field, M. (2012).	Go/No-Go task				Delay Discounting tasks	Controlled Oral Word Association test (COWAT)	
Fernie, G., Cole, J. C., Goudie, A. J., & Field, M. (2010).	Go/No-Go task; Stop task				Delay discounting procedure		

Authors	Response Inhibition	Working Memory	Set Shifting	Planning	Decision Making/ Risk Taking	Flexibility	Overall Measure
Giancola, P. R. (2004).	Stroop test; Go/No-Go task		Trail Making test (B)	Tower of Hanoi; Porteus Mazes		Wisconsin Card Sorting test; Conditional Associative Learning test	
Giancola, P. R., Godlaski, A. J., & Roth, R. M. (2012).							Behavior Rating Inventory of Executive Function—Adult Version
Godlaski, A. J., & Giancola, P. R. (2009).	Stroop test; Go/No-Go task		Trail Making test (B);	Tower of Hanoi; Porteus Mazes		Wisconsin Card Sorting test Conditional Associative Learning test	
Hall, P. A. (2012).	Stroop task; Go/No-Go task						
Hall, P. A., Elias, L. J., & Crossley, M. (2006).	Stroop task						
Hall, P. A., Elias, L. J., Fong, G. T., Harrison, A. H., Borowsky, R., & Sarty, G. E. (2008).	Stroop task						
Hall, P. A., Fong, G. T., & Epp, L. J. (2014).	Stroop task Go/No-Go task						

Authors	Response Inhibition	Working Memory	Set Shifting	Planning	Decision Making/ Risk Taking	Flexibility	Overall Measure
Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008).	Go/No-Go task						
Hall, P. A., Zehr, C. E., Ng, M., & Zanna, M. P. (2012).	Go/No-Go task						
Hoaken, P. N., Assaad, J. M., & Pihl, R. O. (1998).		Paired Associates				Spatial Conditioned Associative Learning task Word Fluency task	
Hofmann, W., Friesse, M., & Roefs, A. (2009).	Stop-signal paradigm	Operation span task					
Houben, K., & Wiers, R. W. (2009).	Stroop task						
Insel, K., Morrow, D., Brewer, B., & Figueredo, A. (2006).		Wisconsin Card Sorting test; Letter-number sequence, Digit span backward, Mental control, and logical memory from the Wechsler					

Authors	Response Inhibition	Working Memory	Set Shifting	Planning	Decision Making/ Risk Taking	Flexibility	Overall Measure
		Memory Scale III; California Verbal Learning test					
Kor, K., & Mullan, B. A. (2011).	Go/No-Go task						
Magar, E. C. E., Phillips, L. H., & Hosie, J. A. (2008).							Dysexecutive Questionnaire
McAuley, E., Mullen, S. P., Szabo, A. N., White, S. M., Wójcicki, T. R., Mailey, E. L., Gothe, N.P, Olson,, E.A., Voss,, M., Erickson,, K., Prakash,, R., & Kramer, A. F. (2011).	Stroop task; Flanker task	Wisconsin Card Sorting task	Dual task; task-switching task				
Menon, C. V., Jahn, D. R., Mauer, C. B., & O'Bryant, S. E. (2013).							Executive Interview 25 (EXIT 25)
Mullan, B., Wong, C., Allom, V., & Pack, S. L. (2011).	Stroop task			Tower of Hanoi	Iowa Gambling task	Wisconsin Card Sorting task	
Patrick, M. E., Blair, C., & Maggs, J. L. (2008).	Go/No-Go task	N-back task					
Schlam, T. R., Japuntich, S. J., Piper, M. E., Gloria, R., Baker, T. B., & Curtin,	Simon task (modified)						

Authors	Response Inhibition	Working Memory	Set Shifting	Planning	Decision Making/ Risk Taking	Flexibility	Overall Measure
J. J. (2011).							
Sharbanee, J. M., Stritzke, W. G. K., Jamalludin, M. E., & Wiers, R. W. (2014).	Cognitive load task	Operation span task					
Sheffer, C., MacKillop, J., McGeary, J., Landes, R., Carter, L., Yi, R., Jones, B., Christensen, D., Stitzer, M., Jackson, L., & Bickel, W. (2012).	Go/No-Go task				Balloon Analogue Risk task; Delay Discounting tasks		Microcog™ Assessment of Cognitive Functioning; Frontal Systems Behavior Scale
Tahaney, K. D., Kantner, C. W., & Palfai, T. P. (2014).			Trail Making test				
Wallace Deckel, A. and Hesselbrock, V. (1996).			Trails test (Wechsler Adult Intelligence Scale-Revised)				
Wettstein, M., Wahl, H.-W., & Diehl, M. K. (2014).			Trail Making test				
Whitney, P., Hinson, J.M., and Jameson, T.L. (2006).		Forward/backward digital span task;	Trail Making test				Dysexecutive Questionnaire

Authors	Response Inhibition	Working Memory	Set Shifting	Planning	Decision Making/ Risk Taking	Flexibility	Overall Measure
		Continuous memory-scanning task					
Wiers, R. W., Beckers, L., Houben, K., & Hofmann, W. (2009).	Stroop test						
Wong, C. L., & Mullan, B. A. (2009).	Go/No-Go task			Tower of Hanoi			

Executive function sub-components are summarized according to the authors' conceptualization of the EF measures they used. In the case that authors did not identify which aspect of EF was being measured, we provided the classification according to neuropsychological references.

Table 2. Executive function and health behavior studies

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	Alcohol consumption					
1	Wallace Deckel, A. and Hesselbrock, V. (1996) Behavioral and cognitive measurements predict scores on the MAST: A 3-year prospective study	Young adults (N=83), half with a positive family history of alcoholism	Wechsler Adult Intelligence Scale-Revised Categories, Trails, and Similarities tests	Self-report of drinking behavior and EF measured at time 1 and time 2 (3 years later).	Change in alcohol consumption from time 1 to time 2 (3-year span) using self-rated responses from Michigan Alcoholism Screening test (MAST)	EF test scores are predictive of changes in MAST scores and in the future alcohol consumption at 3 years after assessment.
2	Whitney, P., Hinson, J.M., and Jameson, T.L. (2006). From executive control to self-control: Predicting problem drinking among college students	Undergraduate university students 18-24 years (N=80); both high- and low-scoring in Rutgers Alcohol Problem Index (RAPI)	Trail Making test; Forward/backward Digital span; Continuous memory-scanning task; Dysexecutive Questionnaire	Subjects scoring in the highest and lowest quartiles of the RAPI were administered EF measures in two sessions	Current consumption from Rutgers alcohol problem index	Self-report measure of executive function was a very strong predictor of being in high- or low-scoring RAPI groups. Students with high levels of negative drinking consequences made fast decisions but displayed high levels of interference from prepotent responses.

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
3	Houben, K., & Wiers, R. W. (2009). Response inhibition moderates the relationship between implicit associations and drinking behavior.	University students (N=71)	Stroop task	EF and alcohol consumption (past week) measured in one online session.	Timeline follow-back method for alcohol consumed in the last week; Alcohol Use Disorders Identification test (AUDIT)	implicit associations were unrelated to drinking behavior when response inhibition was high. In contrast, when response inhibition was low, stronger implicit associations between alcohol and positive affect predicted increased alcohol use and alcohol-related problems.
4	Fernie, G., Cole, J. C., Goudie, A. J., & Field, M. (2010). Risk-taking but not response inhibition or delay discounting predict alcohol consumption in social drinkers.	University students (N=75)	Go/No-Go task; Stop signal task; Delay discounting procedure	EF and alcohol consumption measured (past 30 days) in one session	AUDIT; Timeline Follow Back Questionnaire (TFBQ) Binge Drinking Questionnaire	Risk-taking, but not response inhibition or delay discounting tasks, significantly predicted alcohol use index score after controlling for gender
5	Mullan, B., Wong, C., Allom, V., & Pack, S. L. (2011). The role of executive	Undergraduate university students (N=153)	Tower of Hanoi; Iowa Gambling task; Stroop task; Wisconsin Card Sorting task	Alcohol consumption measured one week after EF measurement	Self-report of having engaged in binge-drinking during past week and greatest number of drinks	Planning ability and inhibition control moderated the relationship between intention and behavior

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	function in bridging the intention-behaviour gap for binge-drinking in university students.				consumed in one drinking session	
6	Christiansen, P., Cole, J. C., & Field, M. (2012). Ego depletion increases ad-lib alcohol consumption: Investigating cognitive mediators and moderators.	Heavy social drinkers ages 18-40 from university (N=80)	Go/No-Go; Controlled Oral Word Association test (COWAT); and Delay Discounting tasks	Lab-based session 1: Associative processes measurement, followed by exposure to ego-depletion task or control manipulation, then alcohol consumption measurement Lab-based session 2: exposure to ego-depletion task or control manipulation, then EF measurement	Volume of beer consumed in bogus taste test	Ego depletion was associated with increased drinking, but no EF measures mediated the effect of ego depletion on drinking. The effect of ego depletion on drinking was mediated by self-reported effort in suppressing emotion and thoughts during the manipulation.
7	Tahaney, K. D., Kantner, C. W., & Palfai, T. P. (2014). Executive function and appetitive processes in the self-control of alcohol use: The moderational role	Individuals with "hazardous drinker" AUDIT scores between 21 and 35 years (N=69)	Trail Making test	Lab-based session: EF and past alcohol consumption measurement, followed by exposure to beer (not consumed), then urge-to-drink and drinking anticipation	Timeline Follow Back 30	Trail Making test (TMT) score moderated the relationship between the urge-to-drink and drinking behavior and the anticipation/drinking relationship among

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	of drinking restraint.			measurement		those with high levels but not low levels of drinking self-control goals. TMT also moderated the anticipation/drinking relationship among those with high self-control goals but not low ones.
8	Sharbanee, J. M., Stritzke, W. G. K., Jamalludin, M. E., & Wiers, R. W. (2014). Approach-alcohol action tendencies can be inhibited by cognitive load.	University students, both heavy and light drinkers (N=51)	Cognitive load task (six-digit memory task); operation span task	Lab-based session: EF and alcohol consumption measured in one session	Amount of alcohol consumed in bogus taste test	Interference suppression inhibited alcohol action tendencies; dysregulated drinkers showed similar skill as regulated drinkers in the study's interference suppression tasks
Alcohol-related aggression						
9	Hoaken, P. N., Assaad, J. M., & Pihl, R. O. (1998). Cognitive functioning and the inhibition of alcohol-induced aggression.	Men aged 18-30 (N=43)	Spatial Conditioned Associative Learning task; Word Fluency task; Paired Associates	Participants randomized to an alcohol intoxication or sober condition, then aggression task was administered, some followed by EF tasks	Modified Taylor Aggression task	EF moderated the alcohol/aggression relationship.

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
10	Giancola, P. R. (2004). Executive functioning and alcohol-related aggression.	Social drinkers between 21-35 years (N=310)	Porteus Mazes; Go/No-Go task; Trail Making test (B); Stroop test; Conditional Associative Learning test; Tower of Hanoi; Wisconsin Card Sorting test	Alcohol aggression measured after alcohol consumption, which was administered after EF measurement.	Modified Taylor Aggression task	EF moderated the alcohol-aggression relationship.
11	Godlaski, A. J., & Giancola, P. R. (2009). Executive functioning, irritability, and alcohol-related aggression.	Social drinkers between 21-35 years (N=313)	Porteus Mazes; Go/No-Go task; Trail Making test (B); Stroop test; Conditional Associative Learning test; Tower of Hanoi; Wisconsin Card Sorting test	Alcohol aggression measured after alcohol consumption, which was administered after EF measurement.	Taylor Aggression task	Irritability mediated the EF/intoxicated aggression
12	Wiers, R. W., Beckers, L., Houben, K., & Hofmann, W. (2009). A short fuse after alcohol: Implicit power associations predict aggressiveness after alcohol consumption in young heavy drinkers with limited	Heavy male drinkers between 17-30 years (N=57)	Stroop test	Aggressiveness questionnaire and EF measured in one session.	Self-report on four questionnaire items -- "After drinking alcohol, I feel..." aggressive, cheeky, hot-tempered, annoyed.	Response inhibition was a significant moderator of the associations/ aggression relationship, indicating a stronger relationship between alcohol power associations and aggressiveness after drinking among those with lower EF.

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	executive control.					
13	Giancola, P. R., Godlaski, A. J., & Roth, R. M. (2012). Identifying component-processes of executive functioning that serve as risk factors for the alcohol-aggression relation.	Healthy social drinkers between 21 and 35 years (N=512)	Behavior Rating Inventory of Executive Function–Adult Version	Alcohol aggression measured after alcohol consumption, which was administered after EF measurement.	Taylor Aggression task	Behavioral Regulation Index (BRI), a BRIEF-A composite measure, was a better predictor than the overall BRIEF-A measure, and was also a moderator of the alcohol-aggression relationship. Each of the sub-components of the BRI were not significant predictors of alcohol aggression.
Dietary Intake						
14	Wong, C. L., & Mullan, B. A. (2009). Predicting breakfast consumption: An application of the theory of planned behaviour and the investigation of past behaviour and executive function.	Undergraduate university students (N=96)	Go/No-Go task; Tower of Hanoi	Breakfast consumption measured one week after EF measurement	Self-report of the number of days in the past week of eating breakfast	Planning ability, but not inhibition, moderated the intention-behavior relationship for low-but not high-intention participants. Those with high intention strength showed a positive association with breakfast consumption regardless of planning ability.

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
15	Hofmann, W., Friese, M., & Roefs, A. (2009). Three ways to resist temptation: The independent contributions of executive attention, inhibitory control, and affect regulation to the impulse control of eating behavior.	Female university students (N=112)	Operation span task; Stop-signal paradigm; Affect misattribution procedure		Candy consumption (as measured by weight) after automatic affective task	Executive attention and response inhibition each moderated the relationship between automatic affective reactions and candy consumption.
16	Allan, J.L., Marie Johnston, M., & Campbell, N. (2010). Unintentional eating. What determines goal-incongruent chocolate consumption?	Undergraduate university students (N=62)	Stroop, Tower, Fluency (all from Delis–Kaplan executive function system)	Chocolate consumption measured 10 minutes after EF measurement.	Amount of chocolate consumed during bogus consumer product test (determined by weighing the chocolate before and after the task)	Response inhibition, but not planning ability, was associated with chocolate consumption.
17	Allan, J.L., Marie Johnston, M., & Campbell, N. (2011). Missed by an inch or a mile? Predicting the size of intention–behaviour gap from	University students (N=50)	Computerized Go/No-Go task; Tower task; Trail Making task; Dysexecutive Questionnaire; Stroop task	Dietary intake measured for three days after EF measurement.	Computerized behavior diary (of fruit and vegetable consumption and high-calorie snacking, as well as four other behaviors) for two work days and one	Task switching, overall executive control measures, and Stroop, but not Go/No-Go task, were significant predictors of the fruit and vegetable intention-

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	measures of executive control.				weekend day	behavior gap.
18	Allom, V., & Mullan, B. (2012). Self-regulation versus habit: The influence of self-schema on fruit and vegetable consumption.	Undergraduate university students (N=209)	Iowa Gambling task; Tower of Hanoi;	Prospective design; fruit and vegetable consumption measured one week after EF measurement	Block Food Frequency Questionnaire	Response inhibition, but not planning, moderated the intention/fruit and vegetable relationship among self-schematics. Among non-schematics, habit was the only significant predictor.
19	Hall, P. A. (2012). Executive control resources and frequency of fatty food consumption: Findings from an age-stratified community sample.	Functionally mobile adults between the ages of 18 and 89 (N=208)	Stroop task; Go/No-Go task	Fatty food and non-fatty food consumption measured one week after EF measurement.	National Cancer Institute's Fat Screener Questionnaire	Response inhibition was associated with consumption of fatty foods, but not non-fatty foods.
Medication adherence						
20	Insel, K., Morrow, D., Brewer, B., & Figueredo, A. (2006). Executive function, working memory, and medication adherence	Community dwelling older adults (N=95)	Wisconsin Card Sorting test; Letter-number sequence, Digit span backward, Mental control, and logical memory from the	Medication adherence monitored with electronic medication monitoring cap for 8 weeks after EF measurement.	Percentage of days that the correct number of medication doses was taken, as measured by medication monitoring cap system	Composite score of several working memory tests was the sole statistically significant predictor of medication adherence. Neither

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	among older adults.		Wechsler Memory Scale III; California Verbal Learning test and composite			general cognition nor a general memory composite score was associated with medication adherence.
Multiple behaviors						
21	Hall, P. A., Elias, L. J., & Crossley, M. (2006). Neurocognitive influences on health behavior in a community sample.	Adults 20–100 years of age (N=216)	Stroop task; Peabody Picture Vocabulary test—Revised	EF and health behaviors measured in the same session.	Self-report of sleep difficulties, exercise frequency; CAGE alcoholism questionnaire	Response inhibition was a statistically significant predictor of alcohol problems, sleep difficulties, and number of pack years smoked but not for exercise frequency.
22	Magar, E. C. E., Phillips, L. H., & Hosie, J. A. (2008). Self-regulation and risk-taking.	Undergraduate university students (N=134)	Dysexecutive Questionnaire	EF and health behavior measured in the same session.	Self-report of current smoking status, age of first cigarette, and problem behaviors associated with excessive alcohol consumption	EF was a predictor of alcohol-related problem behaviors but not age of first cigarette.
23	Patrick, M. E., Blair, C., & Maggs, J. L. (2008). Executive function, approach sensitivity, and emotional	Single female university students (N=72)	N-back task; Go/No-Go task	EF and health behavior measured in the same session.	Self-reported recent alcohol and drug use using Monitoring the Future Questionnaire	Working memory was a statistically significant moderator of the approach sensitivity/alcohol consumption relationship, with

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	decision making as influences on risk behaviors in young adults.					<p>individuals higher in approach sensitivity and better working memory associated with <i>more</i> alcohol use.</p> <p>Response inhibition was a marginally significant moderator of the approach sensitivity/alcohol consumption relationship, and a significant moderator of the emotional decision making/alcohol consumption relationship.</p>
24	<p>Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008).</p> <p>Executive function moderates the intention-behavior link for physical activity and dietary behavior.</p>	Undergraduate university students (N=64)	Go/No-Go task	Physical activity measured one week after EF measurement.	Self-reported number of hours engaged in vigorous physical activity over the past week	Response inhibition moderated the relationship of intention with both physical activity and fruit and vegetable consumption.
25	Black, D. S., Semple, R. J., Pokhrel, P., &	First-year medical students (N=28)	Automated open span task	EF and health behaviors measured	AUDIT; elf report from Web survey questions	Working memory was not statistically

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	Grenard, J. L. (2011). Component processes of executive function-mindfulness, self-control, and working memory-and their relationships with mental and behavioral health.			in the same online session.	about substance use in the past four months	significantly correlated with substance use, harmful alcohol use, or smoking.
26	Booker, L., & Mullan, B. (2013). Using the temporal self-regulation theory to examine the influence of environmental cues on maintaining a healthy lifestyle.	Undergraduate university students (N=152)	Tower of London task; Go/No-Go task; Iowa Gambling task	Health behaviors measured one week after EF measurement.	Self-report of number of days during the past week meeting national guidelines for physical activity, fruit and vegetable consumption, breakfast consumption, sleep, and alcohol consumption	Planning and response inhibition, but not rational decision-making, were associated healthy lifestyle score in unsupportive environments, but not in supportive ones.
27	Menon, C. V., Jahn, D. R., Mauer, C. B., & O'Bryant, S. E. (2013). Executive functioning as a mediator of the relationship between	Rural dwelling English-speaking adults (40+) and older adults of non-Hispanic White and Hispanic origin--both cognitively impaired and healthy (N=456)	Executive Interview 25 (EXIT 25)	Health behaviors measured one week after EF measurement.	AUDIT score Self-report of current smoking status Total number of cancer screenings	EF was associated with smoking status, problem drinking, and cancer screenings. EF fully mediated the relationship between a measure of education quality and smoking

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	premorbid verbal intelligence and health risk behaviors in a rural-dwelling cohort: A project FRONTIER study.					and partially mediated the relationship between education quality and cancer screenings.
28	Hall, P. A., Fong, G. T., & Epp, L. J. (2014). Cognitive and personality factors in the prediction of health behaviors: an examination of total, direct and indirect effects.	Adults 18-89, functionally mobile (N=208)	Stroop task; Go/No-Go task	Physical activity measured for seven days after EF measurement; dietary intake (for the past two weeks); measurement of temporal window for dietary intake was not specified.	Activity as measured by accelerometer; National Cancer Institute Fatty Food Screener	Response inhibition was a significant predictor of a health behavior composite score and partially explained the association between personality factors and health behavior. Response inhibition had the strongest effect in middle and older adult populations.
Out-of-home behaviors						
29	Wettstein, M., Wahl, H.-W., & Diehl, M. K. (2014). A multidimensional view of out-of-home behaviors in cognitively unimpaired older adults:	Cognitively healthy older adults (N=100)	Trail Making test	GPS tracking for four weeks after EF measurement.	Multi-method assessment using GPS and self-report questionnaire	Wettstein et al. (2014) reported that a set-shifting but not X, Y, or Z measure was a moderately significant predictor of an activity engagement measure of out-of-home behaviors (OOHB;

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	examining differential effects of socio-demographic, cognitive, and health-related predictors.					behaviors associated with moving from one location to another and involvement in activities outside the home) among cognitively unimpaired community-dwelling older adults. Working memory measure was a marginally statistically significant predictor of the mean distance from home measure, with individuals with higher WM scores traveling farther distances from home.
	Physical activity					
30	Hall, P. A., Elias, L. J., Fong, G. T., Harrison, A. H., Borowsky, R., & Sarty, G. E. (2008). A social neuroscience perspective on physical activity.	Undergraduate university students (N=124/58)	fMRI; Stroop task	Study 1: GPS tracking for four weeks after EF measurement. Study 2: fMRI imaging conducted one week after accelerometer measurement.	Triaxial accelerometer	More effective engagement of executive attentional and inhibitory networks in participants who showed higher self-regulation in meeting their exercise intentions over the

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
						course of a week than did the “unsuccessful self-regulators.” Response inhibition was a moderator of the intention/behavior relationship.
31	McAuley, E., Mullen, S. P., Szabo, A. N., White, S. M., Wójcicki, T. R., Mailey, E. L., Gothe, N.P, Olson,, E.A., Voss,, M., Erickson,, K., Prakash,, R., & Kramer, A. F. (2011). Self-regulatory processes and exercise adherence in older adults.	Community-dwelling older adults (N=177)	Dual task; Stroop task; Flanker task; Wisconsin Card Sorting task; Task-switching task	Monitoring of exercise classes for 11 months after EF measurement.	Percentage of attendance to exercise classes over the last 11 months of a 12-month exercise program	Stroop task and dual task, but not Wisconsin Card Sorting test, flanker task, or task switching, had significant direct effects on self-efficacy, which had significant direct effects on exercise adherence.
32	Hall, P. A., Zehr, C. E., Ng, M., & Zanna, M. P. (2012). Implementation intentions for physical activity in supportive and unsupportive	Undergraduate university students (N=276)	Go/No-Go task	Physical activity measured one week after EF measurement.	Self-report of number of hours of vigorous physical activity that they had engaged in over the past 7 days using a measure derived from the Stanford 7-day Recall	Response inhibition moderated the intention-behavior relationship in supportive conditions, regardless of implementation intention.

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	environmental conditions: An experimental examination of intention–behavior consistency.					
Sleep hygiene						
33	Kor, K., & Mullan, B. A. (2011). Sleep hygiene behaviours: An application of the theory of planned behaviour and the investigation of perceived autonomy support, past behaviour and response inhibition.	First-year undergraduate students (N=257)	Go/No-Go task	Sleep hygiene measured one week after EF measurement.	Pittsburgh Sleep Quality Index	Response inhibition was the strongest predictor of sleep hygiene.
Smoking						
34	Brega, A. G., Grigsby, J., Kooken, R., Hamman, R. F., & Baxter, J. (2008). The impact of executive cognitive functioning on rates of	Community dwelling older adults (60-99) (N=1338)	Behavioral Dyscontrol Scale	EF and health behaviors measured in the same session.	Current number of cigarettes smoked per day Age of smoking initiation Age of smoking cessation	EF somewhat predicted whether an individual had stopped smoking, but not whether a person had ever smoked, the age at which they started smoking, the age at

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	smoking cessation in the San Luis Valley Health and Aging Study.					which they stopped smoking, or the number of cigarettes smoked per day.
35	Schlam, T. R., Japuntich, S. J., Piper, M. E., Gloria, R., Baker, T. B., & Curtin, J. J. (2011). Cognitive conflict following appetitive versus negative cues and smoking cessation failure.	Smokers enrolled in cessation trial (N=365)	Simon task (modified)	Cessation measured 1 and 7 days after entering clinical trial; EF measured during trial intake process.	Initial cessation remaining abstinent for at least 1 day in the first week post-quit; biochemically confirmed 7-day point prevalence; abstinence 1 week post-quit; number of days smoked in the first 7 days post-quit; biochemically confirmed 7-day point-prevalence abstinence at 8 weeks post-quit	EF impairment was not a significant predictor of cessation outcomes.
36	Sheffer, C., MacKillop, J., McGeary, J., Landes, R., Carter, L., Yi, R., Jones, B., Christensen, D., Stitzer, M., Jackson, L., & Bickel, W. (2012). Delay discounting, locus of control, and	Highly dependent lower SES participants enrolled in intensive cognitive-behavioral treatment (N=97)	Balloon Analogue Risk task; Delay Discounting tasks; Frontal Systems Behavior Scale; Go/No-Go task; Microcog™ Assessment of Cognitive Functioning	Abstinence measured after treatment program; EF measured prior to treatment.	Point prevalence abstinence assessed 1, 2, 3, 4, 8, 12, and 28 weeks after the quit day.using exhaled CO level of 8 ppm or less as measured by Bedfont Smokelyzer	Delay discounting tasks and the Barratt Impulsiveness Scale 11 predicted smoking cessation, but no other EF measures were significant predictors.

	Authors, year, title	Population (N)	EF measures	Temporal aspect	Health behavior measure	EF findings
	cognitive impulsiveness independently predict tobacco dependence treatment outcomes in a highly dependent, lower socioeconomic group of smokers: predicting tobacco dependence treatment outcomes.					

Figure 1. Literature review search flow

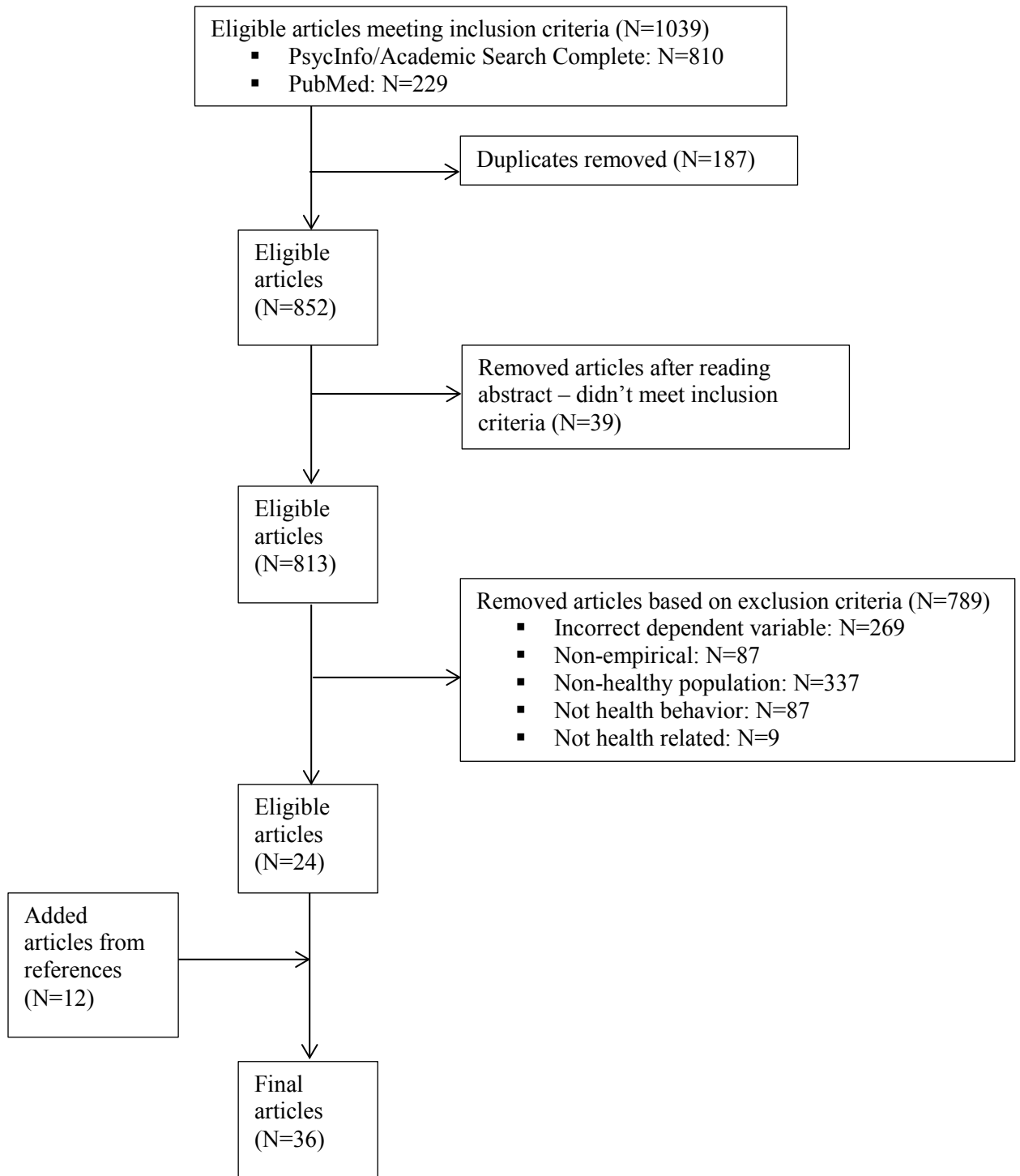
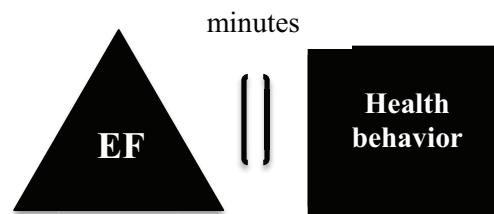
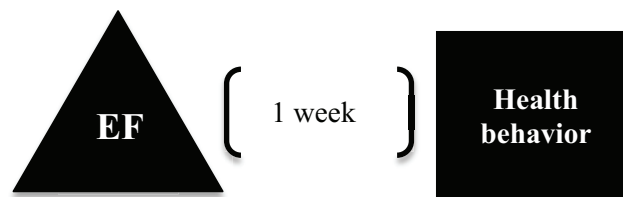


Figure 2. Temporal window of executive function and health behavior measurement

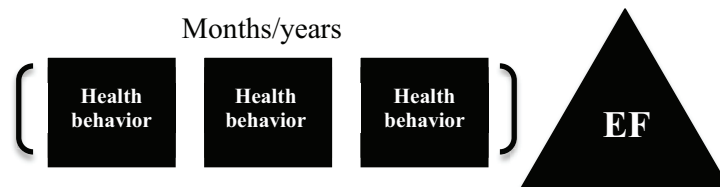
Lab-based studies (n=8)



Short-term follow-up studies (n=12)



Questionnaire studies (n=7)



Long-term follow-up/ monitoring studies (n=6)

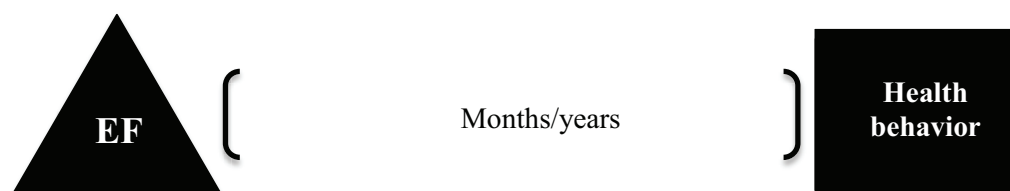
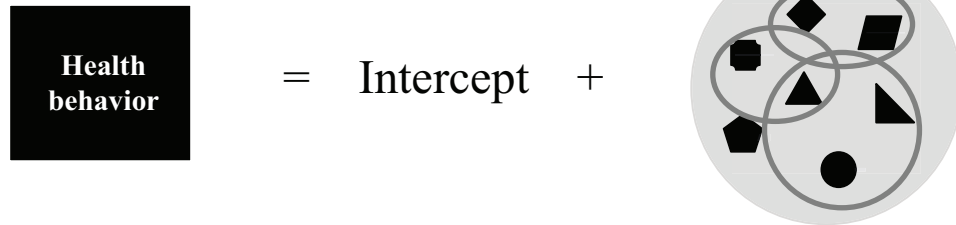
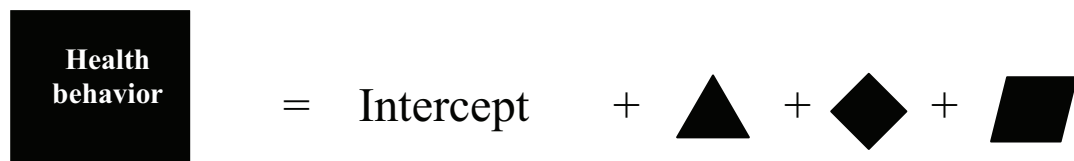


Figure 3. Approaches to the use of EF measures in health behavior

Composite measure



Multiple measures



One measure



CHAPTER 5: EXECUTIVE FUNCTION AND HEALTH BEHAVIOR THEORY

Abstract

Traditional health behavior models largely assume that behavior is predominantly rational. Many other areas of study, including economics and political science, have moved beyond these theories to suggest that human behaviors are not entirely rational. Recent research has expanded traditional theories by incorporating executive function (EF) to reflect that self-regulation needed to maintain healthy behavior. Theories from the addiction sciences offer a related but contrasting perspective by modeling behavior as being affected by EF as well as associative processes. In this chapter, I propose that existing health behavior models would benefit from incorporating automatic process constructs from dual process theories and that our understanding of the role of EF in health behavior can be broadened through an appreciation of dual process models. I first offer an overview of intention-based health behavior theory and dual process models. Next, I compare and contrast two groups of articles from the EF/health behavior literature using intention-based and dual process perspectives, respectively. Finally, I discuss implications for health behavior interventions, suggesting that the addition of automatic processes into more rationality-based models not only offers a more comprehensive view of health behavior but also points to powerful processes that can be harnessed to inform health behavior interventions.

Background

Chronic disease currently accounts for seven of 10 deaths in the United States (Kung, Hoyert, Xu, & Murphy, 2008), and a large proportion of chronic disease is attributed to behavioral factors (Mokdad, Marks, Stroup, & Gerberding, 2004). Unlike the infectious disease prevention of past public health eras that required a one-time behavior for treatment and prevention (e.g., vaccination), the behaviors to prevent and treat chronic disease are acknowledged to be more difficult to change and maintain. Public health models have evolved to better conceptualize this complexity, moving from individual models to more ecological models that acknowledge the numerous influences on health behavior, including physical environment, social norms, and cultural influences, as well as a convergence of biological and cognitive factors as individuals navigate the physical and social environments of their daily lives (Glass & McAtee, 2006; Hall & Fong, 2007).

A growing field of public health research aims to understand and harness these cognitive processes, which researchers have come to describe as operating in two modes: an intentional mode described as “slow,” rational, and deliberate, and an automatic mode described as “fast,” impulsive, and intuitive (Marteau, Hollands, & Fletcher, 2012). Chief among the constructs associated with intentional processes is executive function (EF), which is quite understandable given its cognitive responsibility for goal formation and self-regulation. Executive function represents the intentional, higher-order cognitive abilities associated with making decisions, forming goals, as well as planning, organizing, devising strategies for attaining goals, and when necessary, revising those plans (Coolidge & Wynn, 2001). Executive function has been shown to predict important health behaviors, including treatment adherence (Insel, Morrow, Brewer, & Figueredo,

2006), substance use (Hall, Elias, & Crossley, 2006), stress regulation (Williams, Suchy, & Rau, 2009), rehabilitation behaviors (Solberg Nes, Roach, & Segerstrom, 2009), physical activity (Hall, Elias, et al., 2008), and eating behaviors (Allan, Johnston, & Campbell, 2010; Hall, Fong, Epp, & Elias, 2008; Wong & Mullan, 2009).

Executive function stands in contrast to the brain's more automatic processes, which are performed without intentional direction. Automatic processes are learned and develop over time in response to stimuli and circumstances. Actions, processing schemes, and routines become associated with stimuli and eventually become linked with each other so that a cascade of actions occurs when a stimulus is encountered (Hughes, 2005).

Both intentional and automatic processes play an important role in health behavior, and researchers have called for more research into these mechanisms (Marteau et al., 2012; Williams & Thayer, 2009). As evidence about cognitive processing grows, health behavior models will need to be developed to reflect these new understandings to better explain health behavior and inform interventions aimed at reducing chronic disease.

In this chapter, I propose that existing health behavior models would benefit from incorporating automatic process constructs from dual process theories and that our understanding of the role of EF in health behavior can be broadened through an appreciation of dual process models. I first offer an overview of intention-based health behavior theory and dual process models. Next, I compare and contrast two groups of articles from the EF/health behavior literature using intention-based and dual process perspectives, respectively. I will discuss these findings to make a case for adapting

current health behavior theories. Finally, I will discuss implications for health behavior interventions and will identify areas for future research.

Intention-Based Theory

Historically, most health behavior theory has focused on rational thought and therefore on intentional processes. Theories such as the Social Cognitive Theory (Bandura, 1986), the Theory of Reasoned Action (Fishbein & Ajzen, 1975), the Theory of Planned Behavior (Ajzen, 1991), the Health Belief Model (Janz & Becker, 1984) and the Stages of Change model (Prochaska, DiClemente, & Norcross, 1992) assume that behavior is predominantly rational and driven by “reasoned, conscious, and intentional acts that require a person’s volitional control or willpower in order to be effective” (Hofmann, Friese, & Wiers, 2008).

Most of these theories describe an expectancy-value approach in which behaviors result from intentions based on a deliberative process about antecedent factors such as attitudes, beliefs, and perceptions (Gibbons et al., 2009), and are therefore labeled by some as a “consequentialist” view of behavior because of the emphasis on the contemplation of these factors that happen before the behavior (Loewenstein, Weber, Hsee, & Welch, 2001).

Intention is reported to be one of the most often-studied constructs in health behavior (Godin & Kok, 1996), possibly because of its widespread report to explain a considerable amount of variance in health behavior (Armitage & Conner, 2001; Brug, van Lenthe, & Kremers, 2006). It is universally acknowledged, however, that not all intentions translate into behavior. This discrepancy between intentions and actual behavior has been termed the “intention-behavior gap” and reflects the black-box nature

of the underlying psychological processes that enable the realization of intentional behavior (Sniehotta, 2005). The intention-behavior gap is largely attributed to individuals called “inclined abstainers” who intend to act, but fail to do so (Orbell & Sheeran, 1998; Sheeran, 2002).

Much health behavior research has been dedicated to elucidating the intention-behavior gap, and EF appeared within the public health literature as one explanatory factor in an article by Peter Hall and Geoffrey Fong in 2007 (Hall & Fong, 2007). Their Temporal Self-regulation Theory (TST) suggests that intention does drive behavior, but that the short-term costs (despite long-term gains) of many health behaviors are demotivating. These temporal differences, which underscore a “now vs. later” dilemma, require individuals to effortfully regulate their behavior to meet long-term goals. The theory suggests that the capacity to do so depends upon the convergence of biological, cognitive, and social factors and names EF as the cognitive resource that allows individuals to sustain attention to long-term goals.

This understanding begins to soften the rational actor model by recognizing that logically formed intentions aimed at long-term benefit are often sabotaged by the “palpable seduction” of unhealthy behavior (Hall & Fong, 2007, p. 7) that places a high cognitive load on human self-regulatory ability. This theory acknowledges that in addition to intention, past behavior, self-regulatory capacities, and environment play into behavioral outcomes, but the main focus of research instigated by this theory is on explaining the intention-behavior gap using EF.

Dual Process Theory

Dual systems theories can be traced to the theoretical considerations of 19th century American psychologist William James, who described contrasting automatic and reasoning cognitive processes. The idea of contrasting cognitive processes determining behavior is found consistently throughout psychology and has developed further in several dual process models in modern psychology (Metcalf & Mischel, 1999; Sloman, 1996; Smith & DeCoster, 2000; Strack & Deutsch, 2004), behavioral economics (Kahneman & Tversky, 1979), and persuasion (Petty & Cacioppo, 1986). These theories are defined by the conceptualization of behavior as emerging from two different processes – one that is slow, conscious, and controlled, and one that is fast, unconscious, and automatic.

One dual process theory that increasingly is being applied to addictive behaviors is Strack and Deutsch's (2004) Reflective-Impulsive Model (RIM). This theory distinguishes two information-processing modes: an impulsive mode that is fast, implicit, and draws upon the store of associations that the person has acquired over many experiences; and the reflective mode, which is slow, based on logic rather than associations, and is accessed intentionally.

Impulsive Processes

Hofmann et al. (2009) describe several features of the impulsive system in the RIM. First, the impulsive processing mode develops gradually over time, growing with repetition as associative clusters are formed in long-term memory in relation to exposure to specific stimuli. For example, a feeling of warmth and wellbeing may be associated when sharing a family meal. Over time, this association may grow so that when visiting family – or even talking to a family member on the phone – individuals are more likely to

eat, even if they are not hungry. The repeated positive affect (warmth and wellbeing) that accompanies the stimulus (being with a loved one) becomes associated with the behavioral input (eating). After they have been formed, these associations and behavior outcomes become automatic, needing no attentional resources and not even requiring that the individual be aware that the association exists (Gawronski & Bodenhausen, 2006; Strack & Deutsch, 2004). In fact, a person may be perplexed as to why she finds herself wandering into the kitchen to have a snack every time her sister calls. Impulses typically are associated with a strong positive hedonic reaction to a particular stimulus, are aimed at short-term gratification, and rouse a desire to perform a specific behavior (Hofmann et al., 2008), such as eating in the example described above.

Such behaviors are largely thought to be fueled by internal biological drives (such as hunger and thirst) (Hull, 1943), salient environmental cues (Steele & Josephs, 1990), or past behavior (Ouellette & Wood, 1998). Many “default” reflexes, such as the fight-or-flight response, are thought to emanate from the lower brain stem and limbic circuitry, areas of the brain that are associated with survival and that do not require directed thought or pre-existing intention.

Reflective Processes

In contrast, reflective processes use higher-order thinking to guide behavior in accordance with longer-term goals. The RIM conceptualizes that in a given situation, the reflective system compares the long-term goals with the situation at hand, and if a discrepancy is detected, will decide to override the offending behavior.

The reflective system is largely synonymous with the self-regulation aspect of EF: the ability to discern the appropriateness of, and override when necessary, the automatic

response to increase the potential for a better result in the future. One's ability to override these responses is thought to occur in the brain's prefrontal cortex (PFC), which receives input from all sensory modalities and the outside world to react to stimuli (Suchy, 2009). The role of the PFC is essentially to interrupt and "stretch out" time between a stimulus and response (Tucker, Derryberry, & Luu, 2000). This allows higher-order thinking to compare and discard many possible plans or strategies in favor of what is likely to be the most beneficial in the long run, that is, "to be reflective rather than impulsive" (Lewis & Todd, 2007, p. 410).

A notable limit to the reflective system, however, is that these EF processes require a great deal of mental energy. Gailliot et al. (2007) reported that an act of this type of self-regulation requires more blood glucose than do other mental acts. This means that such mental strength is a valuable resource that is limited in quantity, working similarly to muscular strength, which is depleted as muscles are used and which is restored only after rest (Schmeichel & Baumeister, 2004).

Behavior in the Balance

Hofmann et al. (2008) highlight that impulses do not always, but often, conflict with reasoned action. In these cases of conflict, the RIM describes a type of tug-of-war between the two systems for a course of action. Which system wins depends on the relative strength of activation for the competing behavioral plan of action. Hofmann et al. (2009) note that this competition is not necessarily symmetrical, with certain situational and dispositional conditions (e.g., stress, alcohol intoxication, cognitive load) shifting advantage to one system or another (Strack & Deutsch, 2004). In these situations, the reflective system may fail to initiate its overriding/inhibitory actions, and the impulsive

system is likely to be more influential. This is described by Baumesiter, Heatherton, and Tice (1994) as self-regulation failure.

Intention-Based and Dual Process Theories in Health Behavior Literature

A review of the health behavior literature regarding EF and health behavior (see Chapter 4 for methodological details) revealed that intention-based, rational actor models and dual process models were the two major theoretical perspectives underpinning EF/health behavior research. Ten articles used an intention-based approach, and seven articles used a dual process model perspective. This section will compare and contrast various features of these two groups of articles (see Tables 1 and 2).

Health Behaviors Studied

These two groups of articles were found in different literatures and but covered some similar health behaviors. The intention-based articles primarily appeared in the health psychology literature, while the dual process articles were published in the addiction and pharmacology literature.

Both groups of articles focused on health behaviors of concern to public health, though the each of the groups was more likely to emphasize particular behaviors. Dietary intake (n=4) was the most frequently studied behavior by the intention-based group, followed by physical activity (n=2), sleep hygiene (n=1), and alcohol consumption (n=1). One article covered both physical activity and dietary intake, and one article studied an overall measure of health behavior. On the other hand, the behaviors studied by the dual process articles were mainly related to alcohol: alcohol consumption (n=5) and alcohol-related aggression (n=1). One study dealt with candy consumption.

Theoretical Approaches for the Role of Executive Function

As was highlighted above, the defining difference between the two groups was the theoretical approach underpinning the research, though there were some similarities in the ways in which the groups conceptualized the role of EF. The intention-based articles focused on EF as moderating the intention-health behavior gap and specifically theorized that the self-regulatory ability of EF would help individuals to keep health goals in mind and to resist distractions and temptations to intended behavior. These articles often cited the Theory of Planned Behavior (n=8), the Theory of Reasoned Action (n=4), and Hall's Temporal Self-Regulation Theory (TST) (n=7).

The dual process articles also drew on the inhibitory aspect of EF, suggesting that EF's inhibitory control is in contest with the associative processes that draw individuals to substances. These articles theorized that behavior is generally the outcome of the relative strengths of these two systems, with EF being able to override the impulsive processes but that EF requires both motivation and abilities that are not always available (Wiers et al., 2007). Several of these articles cited the RIM as their guiding model (n=5).

Key Constructs

The intention-based and dual process theories studied different constructs. As its label suggests, the intention-based articles focused on health behavior intentions, modeling them as a key variable. This was typically measured by survey questions such as "How often do you intend to exercise in the next week?". Intention was consistently associated with the health behaviors studied, explaining 3% to 63% of the variance in physical activity, fruit and vegetable consumption, snacking, breakfast consumption, and sleep hygiene. However, in several studies (Booker & Mullan, 2013; Hall, Fong, et al., 2008; Kor & Mullan, 2011), the predictive power of intention on health behavior was

weakened or rendered non-significant when past behavior was included in the regression model.

Four articles tested whether EF modified the relationship between intention and health behavior. In all four articles, EF was found to moderate the relationship. In three of the articles, intention was a stronger predictor of health behavior in individuals with high levels of EF. This was not the case in breakfast consumption, in which those of low intention and high EF (in the form of planning ability) were more likely to eat breakfast.

As mentioned previously, intention was not necessarily the strongest predictor of health behavior, sometimes being overshadowed by other constructs. Past behavior was a key factor in many of the health behaviors and was associated with physical activity, dietary intake, and breakfast consumption (alone explaining 74% of the variance in that behavior), sleep hygiene, as well as an overall measure of health behavior (Booker & Mullan, 2013). Past behavior was not found to be a predictor of fruit and vegetable consumption in one study (Allom & Mullan, 2012); however, a related construct (habit) was significant when the results were stratified by self-schema. Individuals who did not perceive healthy eating to be important or self-descriptive and who had low intentions were more likely to translate intention into action if they had previously formed a strong habit.

Additionally, different behavior patterns were detected by a few authors of intention-based articles who considered different types of environments. Booker and Mullan (2012) reported that planning and response inhibition (RI) were associated with health behavior in unsupported environments but were not associated in supportive environments. Decision making was not associated in either type of environment, but

behavioral prepotency (as measured by a question of past behavior) was associated with health behavior in both supportive and unsupportive environments. Additionally, Hall et al. (2012) reported that in supportive environmental conditions, EF moderated the intention-behavior relationship, such that those with high levels of EF were more likely to realize their goals than were those with low levels of EF. This relationship held even when controlling for past behavior.

In contrast, the key constructs in the dual process articles largely focused on associative processes. Houben and Weirs (2009) and Sharbanee et al. (2014) reported that at least one aspect of EF was a moderator of the alcohol associations/drinking behavior relationship, suggesting that EF ability determines whether alcohol associations predict drinking behavior. Hofmann et al. (2009) reported that executive attention and RI each moderated the relationship between automatic affective reactions and candy consumption. Wiers et al. (2009) reported that RI was a significant moderator of the associations/aggression relationship, indicating a stronger relationship between alcohol power associations and aggressiveness after drinking among those with lower EF. Fernie et al. (2010) reported that a measure of risk-taking, but RI nor delay discounting, was a significant predictor of alcohol use in university students.

Interestingly, one dual process article included intentions as part of its research and found a similar role for EF as did the intentions-based researchers -- that an EF measure moderated the relationship between the urge-to-drink/drinking relationship and the anticipation/drinking relationship among those with high levels but not low levels of drinking self-control goals (i.e., intentions) (Tahaney, Kantner, & Palfai, 2014).

Authors of these articles underscored the importance of both the impulsive and reflective processes, explaining that either process alone is necessary, but not sufficient, for health behavior. Wiers et al. (2009) suggested that it is the coupling of an EF deficit with the relevant associative process that is associated with poorer behavior, explaining that impulsive behavior (such as aggression, unsafe sex, alcohol or drug use) is not merely a matter of low EF abilities, but also an associative process that leads to a particular behavior. Conversely, Sharbanee et al. (2014) suggested that while associative processes can account for motivation to consume alcohol, they alone are insufficient for dysregulated drinking.

Recommendations for Impacting Health Behavior

Articles in the intention-based literature generally did not make recommendations about increasing intention to promote healthy behavior. The most common recommendation (n=7) was for the promotion of implementation intentions, an “if-then” technique that prepares an individual to respond to potentially tempting situations by pre-determining a course of action (e.g., “if they serve cake at dinner, I’ll ask for a fruit plate instead”). Six articles recommended that their findings point to the need to restructure environments to reduce the self-regulatory demands and to make unhealthy choices more difficult. A few articles encouraged health promotion to children to increase habit strength over the course of the lifetime, and several articles recommended techniques to increase self-regulation.

Articles in the dual process group were less likely to suggest intervention implications. They generally suggested that their findings would help to support and further refine the theoretical understanding of dual process theory. Some authors did

suggest that future research could lead to training and treatment procedures aimed at countering associative processes by enhancing EF.

Expanding Traditional Health Behavior Models

The foundation of traditional health behavior theories is based on a rational thinking model. Many other areas of study, including economics and political science, have moved beyond these theories to suggest that human behaviors are not exclusively governed by rationality (Goodson, 2010).^{***} Some public health researchers have suggested that public health also abandon rational actor models, citing their limitations in capturing real-life behavior. In an effort to better represent the importance of self-regulation in health behavior, researchers have added EF to rational actor models. This implicitly acknowledges that key factors are missing that would make these models more reflective of real-life behavior. Specifically, most articles in the intention-based group theorized that EF provides individuals with the self-regulation ability needed to resist temptation, maintain attention to long-term goals, and make rational (rather than emotional) decisions.

However, this acknowledgement stops short of specifying what those factors are and how to include them in a health behavior model. The result is a model that points to a possible mechanism but prevents models from fully explicating the potential processes that impact health behavior actions, resulting in a black box that remains fairly dim. By considering intention-based and dual process explanations for the role of EF in health

^{***} It should be noted, however, that the rational actor model does have its place. Gibbons (2009) points out that many types of health behaviors that do require forethought and deliberation, and these types of behaviors are well-predicted by intention.

behavior, this literature review revealed an alternative way to construct more comprehensive models. The dual process model acknowledges that human behavior is largely driven by non-rational processing and points to what those processes are in certain behaviors. It also offers a specific explanation for the ways that environmental factors impact health behaviors.

Executive function can provide a crucial link for integrating dual process model constructs into rational actor models. Results from the intention-based articles suggest that EF is what helps individuals translate intention into behavior. Dual process models highlight that to do so, EF must overrule the competing automatic processes that are usually (but not always) at odds with more rationally driven thought. The dual process articles described in this chapter provide evidence that these models are helpful in predicting certain health behaviors. Incorporating dual process theory's perspective about the role of EF in overriding associative processes into rational models may provide a more modern account of human behavior that is consistent with evidence from psychology and social neuroscience.

Furthermore, this analysis also has important implications for expanding understanding about the way in which EF impacts health behavior, offering a more nuanced explanation of its role. The intention-based literature operates from what some authors call a deficit model, which suggests that lower levels of EF are associated with poorer health behavior. Several dual process model authors suggest that the deficit model is a limited paradigm and that decreased EF is not enough to explain poorer behavior. Instead, they point to the crucial combination of an EF deficit paired with the relevant

associative process that provides the motivation to engage in impulsive choices and results in poorer behavior.

This understanding can also help to shed light into the black box of the intention-behavior gap. The dual process models provide a reasonable explanation of the factors that make intention so difficult to realize. That is, these models acknowledge that to translate intentions into healthy behavior, individuals must override innate and unconscious forces in opposition to rational intentions. As evidence, one author found that intention can play an important role in the battle between reflective and associative processes to determine alcohol consumption behavior. In these findings, EF moderated the associative processes-alcohol consumption relationship among those with high intention but not among those with low intentions (Tahaney et al., 2014). It is possible that these intentions reinforce the strength of the reflective system (in the form of EF) to positively affect behavior.

The addition of automatic processes into more rationality-based models not only offers a more comprehensive view of health behavior but also points to powerful processes that can be harnessed to inform health behavior interventions. Automatic behaviors are effortless and immediate. This makes them especially powerful, which is something that corporate marketers know and employ regularly. If associative processes can be used to make healthy behavior automatic, however, they could be an influential force in public health. Rather than interventions based on intention and willpower, interventions based on automatic processes would have a potential benefit of being more sustainable, as these processes require little of energy-costly EF resources.

Marteau, Hollands, and Fletcher (2012) take this approach and strongly advocate that health behavior interventions shift away from an informational and intentions-based approach, as it “is fundamentally limited, given that it is based on a view of human behavior that is at odds with psychological and neuroscientific evidence that much human behavior is not actually driven by deliberation upon the consequences of actions, but is automatic, cued by stimuli in the environment, resulting in actions unaccompanied by conscious reflection” (Marteau et al., 2012, p. 1492).

This is the thinking behind “nudge” interventions, defined as “any aspect of the choice architecture that alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives” (Marteau et al., 2012). These interventions rely on choice architecture, a term coined by Thaler and Sunstein (2008), to describe the way that choices are presented to consumers. Choice architecture relies on an understanding of how individuals absorb, process, and react to information from their environments, including the associative processes triggered by environmental cues. Nudge interventions shape choice designs that steer individuals toward a healthy decision without making it mandatory. Examples include making higher-fat items on a salad bar more difficult to reach (Rozin et al., 2011) and making elevator move at slower speeds so as to make taking the stairs more appealing (Faskunger, Poortvliet, Nylund, & Rossen, 2003).

Marteau et al. (2012) also suggest two specific ways in which dual process theory can be considered in interventions: 1) altering the environmental stimuli so that healthy choices do not require as much conscious deliberation and 2) targeting the automatic processes to change how an individual responds to environmental cues.

Areas for Future Research

Because dual process theory has not yet been widely applied in public health (the largest application is in persuasive health communication), there are many areas for future research. First among these would be to test dual process theory's predictive and explanatory power with health behaviors beyond addictive substances. Hofmann et al. (2008) applied dual process theory to candy consumption and reported that several aspects of EF did moderate implicit associations and candy consumption (which arguably could be considered an addictive substance). Similar studies should be conducted with other health behaviors. It is worth considering whether dual process theories predict health-promoting behaviors as well as risky health behaviors; it may be that the RIM is appropriate only for behaviors associated with an aspect of impulsivity. Additionally, specific dual process theories may need to be developed for different types of health behaviors. As mentioned previously in this chapter, several dual process theories exist to explain behaviors ranging from economic decisions to alcohol consumption. Along with these different theories come different aspects of the fast processes that likely vary depending on the behavior of interest. Some work will be needed to determine the specific fast processes that lead to various types of health behavior. This is especially important, as Hofmann et al. (2009) have specifically noted that much health behavior research has been devoted to self-regulation and comparatively little to impulses and associative processes. It will be important to bring balance to this trend to create effective interventions.

Marteau et al. (2012) also acknowledge that while nudge interventions acknowledge automatic processes in ways that other theories and interventions do not, there is a need for both primary research and synthesis of existing evidence to examine

the effectiveness and acceptability of interventions that target automatic processes. This would include determining which interventions work for various populations and circumstances.

Conclusion

Public health faces a daunting task in aiming to reduce chronic disease, especially in modern society, which, as Hall et al. (2007) suggest, “largely pulls for unhealthy behaviors as the default” (p. 445). To do so, health behavior researchers and interventionists need behavior models that are shaped by current understanding of the various forces that influence behavior. The neurocognitive sciences have grown exponentially since traditional health behavior models were developed and can offer powerful insights into the cognitive processes that drive behavior. The inclusion of EF into traditional models is a step in this direction, and this chapter has provided ways in which that work can be furthered. Specifically, these models can point to the weight of associative and other automatic processes – an influence that other sectors of society have acknowledged and exploited, in many cases to the detriment of the public’s health. By including these factors in our models, public health will have a more realistic framework from which to promote healthy behavior.

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List of Tables

Table 1. Intention-based theory articles and dual process-based articles

Table 2. Key features of Intention-based theory articles and dual process-based articles

Table 1. Intention-based theory articles and dual process-based articles

Intention-Based Theory Articles (N=10)	Dual Process-Based Articles (N=7)
Allan, J. L., Johnston, M., & Campbell, N. (2010).	Christiansen, P., Cole, J. C., & Field, M. (2012).
Allan, J. L., Johnston, M., & Campbell, N. (2011).	Fernie, G., Cole, J. C., Goudie, A. J., & Field, M. (2010).
Allom, V., & Mullan, B. (2012).	Houben, K., & Wiers, R. W. (2009).
Booker, L., & Mullan, B. (2013).	Hofmann, W., Friese, M., & Roefs, A. (2009).
Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008).	Sharbanee, J. M., Stritzke, W. G. K., Jamalludin, M. E., & Wiers, R. W. (2014).
Hall, P. A., Elias, L. J., Fong, G. T., Harrison, A. H., Borowsky, R., & Sarty, G. E. (2008).	Tahaney, K. D., Kantner, C. W., & Palfai, T. P. (2014).
Hall, P. A., Zehr, C. E., Ng, M., & Zanna, M. P. (2012).	Wiers, R. W., Beckers, L., Houben, K., & Hofmann, W. (2009).
Kor, K., & Mullan, B. A. (2011).	
Mullan, B., Wong, C., Allom, V., & Pack, S. L. (2011).	
Wong, C. L., & Mullan, B. A. (2009).	

Table 2. Key features of intention-based theory articles and dual process-based articles

	Intention-Based Theory Articles (N=10)	Dual Process-Based Articles (N=7)
Journals	Addictive Behaviors Appetite British Journal of Health Psychology Journal of Experimental Social Psychology Journal of Sport & Exercise Psychology Psychology and Health	Alcoholism: Clinical and Experimental Research Pharmacology, Biochemistry and Behavior Journal of Experimental Social Psychology Drug and Alcohol Dependence Experimental and Clinical Psychopharmacology Drug and Alcohol Dependence Psychopharmacology
Health behaviors	Dietary intake (n=4) Physical activity (n=2) Physical activity and diet (n=1) Sleep hygiene (n=1) Alcohol consumption (n=1) Multiple behavior index (n=1)	Alcohol consumption (n=5) Alcohol aggression (n=1) Dietary intake (n=1)
Key constructs	Intention Past behavior/behavioral prepotency/habit Perceived behavioral control Social norms Environment Self-schema	Associative processes <ul style="list-style-type: none"> • Approach sensitivity • Implicit alcohol associations • Alcohol bias • Associative processes • Automatic affective reaction • Risk Taking
Intervention recommendations	Implementation intentions Restructuring environments Self-regulation training Increasing habit strength	Techniques to enhance executive function

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CHAPTER 6: DISCUSSION OF RESULTS AND PUBLIC HEALTH IMPLICATIONS

Introduction

The goal of this dissertation was to explore the association, theoretical underpinnings, and methodological issues of executive function (EF) as a salient construct for better understanding health behavior. Specifically, this dissertation's aims were to: 1) to determine whether the association between EF score was associated with older adults practicing healthy behavior after controlling for other factors, 2) to investigate the current literature on EF and health behavior, considering measurement of EF, the type and nature of health behavior measured, and theoretical explanations of the relationship, and 3) to consider ways that EF can be represented in health behavior models to more fully conceptualize health behavior.

The purpose of this chapter is to review and synthesize the findings of the research conducted in support of these research aims and to place them in the context of current and future public health research. This chapter will summarize the findings of the each analysis, address overall study strengths and weaknesses, and provide a higher-level perspective on EF and health behavior. Finally, the chapter will fit these findings into the current state of behavioral public health research and intervention and will suggest areas for future research and intervention.

Discussion of Executive Function and Health Behavior Findings

Findings from these analyses identified a small but positive association between EF score and overall health behavior as well as for physical activity and smoking after controlling for several sociodemographic factors. These findings add to a small but growing area of research and are fairly consistent with other similar studies in the literature in finding an association between EF and the same health behaviors. Similar to this study, two articles in the literature also reported an association between EF and some

type of composite health behavior measure. Also similar to this study, an association between at least one aspect of EF and physical activity was reported by all but one of the four studies in the literature review that investigated this relationship. However, while this study reported an association between EF and the average number of daily cigarettes smoked, results about this relationship in the literature were more mixed. Most articles examining EF and smoking used a different outcome measure (cessation success), but of the two that measured number of cigarettes smoked, one article reported an association and one reported that EF did not predict number of cigarettes smoked daily. Additionally, two articles used smoking status as an outcome measure; one article reported an association between EF and smoking, and one reported no association.

Several findings from this study were inconsistent with the literature. This study did not find an association between EF and dietary intake, while all studies in the literature review that examined aspects of diet in the literature reported a positive association. There could be several explanations for this. First, diet is acknowledged to be a highly habitual behavior, and most of the studies in the literature review articles were among university student populations who likely haven't yet established their eating habits. Comparatively, this study was conducted among an older adult population that likely has a very well-established dietary habit, suggesting that EF is not called upon to make dietary choices. Second, most of the dietary studies in the literature review looked specifically at fruit and vegetable intake or snacking/candy/chocolate consumption rather than overall diet quality. Taken together, it may suggest that EF is associated with intentional eating behaviors – those to be avoided (e.g., high calorie snacking and candy consumption) and those to be consciously consumed (e.g., fruits and vegetables), while

not on a more overall measure of dietary quality, especially in studies of older adults with strongly established and healthful eating habits who do not need to call on EF to eat healthfully.

This study found that EF was not associated with alcohol consumption, while literature review results reported a consistent pattern of EF's association with alcohol consumption. Most of the literature review articles, however, used a dual process approach to model this relationship, suggesting that EF alone is not enough to predict alcohol consumption but instead should be considered along with associative processes. Additionally, this study was among an older population that drank moderately compared to the younger populations studied by the literature review articles who may be more likely to binge drink.

Among the important findings of this study is that EF moderated the age/health behavior relationship for several health behaviors, suggesting that EF might diminish the negative relationship between age and overall health behavior, physical activity score, and alcohol consumption. This is a similar finding to that in a study by Hall, Fong, and Epp (2014), which reported that a measure of response inhibition had the strongest effect on health behavior in middle and older adult populations, as compared to younger populations. These authors suggested that the finding may also be unique to older adult populations, where the distribution of EF is often wider, providing more predictive power because of more variability.

These findings should also be taken in the unique context of this study population that includes a relatively large proportion of African Americans (39%) with moderate to high tibia lead levels from lifetime cumulative environmental lead exposure that is

associated with lower EF. Furthermore, research with this population has identified that living in neighborhoods characterized by a high level of psychosocial hazards (defined as stable and visible features of neighborhood environments that give rise to a heightened state of vigilance, alarm, or threat in residents) exacerbates the adverse effects of lead exposure in EF (Glass et al., 2009).

Literature Review Findings

Most studies in this literature review reported associations between EF and health behavior, including physical activity, dietary intake, smoking cessation, alcohol consumption, alcohol-related aggression, medication adherence, sleep hygiene, and out-of-home behaviors. The compilation of these findings points to the contributions of EF to maintaining healthy behavior and avoiding unhealthy behavior. Associations between individual aspects of EF and health behavior, however, were more variable. No clear pattern was detected, though the most consistent finding was with response inhibition, which supports for Miyake and Friedman's (2000) suggestion of response inhibition as the common ability underlying EF in general.

Executive function is a relatively new construct in public health behavior research, and this literature review identified several methodological aspects that have yet to be standardized. First, the research represented by this literature review reflects a wide variation in approaches to EF measurement. The sheer number of different neuropsychological tests was remarkable, with 45 different tests used. Papers in this review tended to fall into one of four main approaches to assessing EF and health behavior: 1) measuring more than one aspect of EF and using the measures separately in analytic models; 2) concentrating on measuring only one aspect of EF; 3) using a

composite measure of EF comprising tests of various EF aspects; and 4) using self-assessments of EF ability based on everyday life situations.

Second, the current literature lacks a clear conceptualization about the temporal relationship between EF and health behavior. The articles in this study showed considerable variation in the time elapsed between the measurement of EF and health behavior – time ranging from minutes to several years. Several authors of articles included in the literature review commented on the correspondence of time elements between EF and health behavior measures and the need to further explore the longer-term effects of EF on health behavior.

For the most part, articles in this study seemed to fall into two temporal categories. The first group, representing more than half of the all the studies reviewed, investigated health behaviors in a time period very close to the measurement of EF, ranging from less than an hour to about one week. The second group, mostly follow-up studies, examined the EF/behavior relationship over a time period of months or years.

Inherent throughout this research is the assumption that EF is a static ability – that EF at one measurement point would be the same or similar when health behavior was assessed, regardless of how far apart the two were measured. While research suggests that individual variation in EF abilities is largely genetic (Friedman & Miyake, 2008), researchers have also described the ability to build EF with training (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008), as well as the phenomenon of depleting EF by taxing it (Baumeister, Heatherton, & Tice, 1994; Schmeichel & Baumeister, 2004).

Executive Function and Health Behavior Theory Findings

The thesis of this analysis posited that traditional health behavior models would benefit from integrating dual process model constructs and suggested that EF provides a crucial link for doing so. The findings of a review of the theoretical underpinnings of two groups of articles studying EF: 1) an intention-based approach, which describe health behavior using an expectancy-value approach in which behaviors result from intentions based on a deliberative process about antecedent factors like attitudes, beliefs, and perceptions (Gibbons et al., 2009) and 2) a dual process model perspective, which considers health behavior to emerge from two different processes – one that is slow, conscious, and controlled, and one that is fast, unconscious, and automatic. The intention-based articles suggested that EF is what helps individuals translate intention into behavior. Dual process models highlight that to do so, EF must overrule the competing automatic processes that are usually (but not always) at odds with more rationally driven thought.

One challenge of intention-based theory is an acknowledged gap between individuals' intentions and their actual behavior. A consideration of dual process theory can help to shape hypotheses about some of the factors that contribute to this gap. The dual process models acknowledge that in order to translate intentions into healthy behavior, individuals must override innate and unconscious forces in opposition to rational intentions. Most of these articles suggest that associative processes – essentially the “draw” to unhealthy behaviors – are an important factor in health behavior and one that requires a considerable amount of EF.

Strengths and Limitations

This dissertation offers a well-rounded consideration of EF and health behavior, from the theoretical, methodological, to the analytical and practical, and like all research endeavors, this dissertation has strengths and limitations.

Strengths of the quantitative study include a rich data set from a cross-section of urban older adults with wide range of socio-economic characteristics. The measure of EF used three well known, valid and reliable neuropsychological tests. Socioeconomic status was measured very carefully and fully for this population of older adults. While health behaviors measures were all self-reported, several were measured by instruments known to have high levels of validity and reliability.

Limitations of this study were consistent of analyses of EF/health behavior studies in the literature. First, the measure of EF used in this study was a composite measure of three different neuropsychological tests aimed at measuring different aspects of EF, but were not necessarily representative of the three most widely recognized EF sub-component in order to create a unified measure of EF representative. Additionally, this research did not present results of the individual EF sub-components as predictors of health behavior. Doing so may have provided evidence that might illuminate more of the role of EF in health behavior.

The second common limitation of EF/health behavior research involves the temporal relationship between the measurement of EF and the overall health behavior measure. In the analysis of the overall measure, the EF variable was an average of the EF measurement from both visit 1 and visit 2, which were an average of 15.6 months apart, and the overall health behavior measure was a composite of four health behaviors measured during two different visits, with smoking and alcohol consumption being

measured at visit 1 and physical activity and dietary intake measured at visit 2. The likely result of this is that health behavior was being predicted by a measure of trait EF.

Additionally, because of this time relationship, it is not possible to tease out an association that is known to be bi-directional. Because of the cross-sectional nature of this analysis, it cannot be said that it is an individual's EF that contributes to better health behavior. Indeed, a well-established literature exists supporting the positive impact of physical activity, especially aerobic exercise, on cognitive performance, including EF, pointing to potential anatomical changes and structural integrity of the brain brought about by physical activity (Colcombe et al., 2006; Erickson et al., 2011; Voss, 2010).

Public Health Implications

Because public health aims to improve health behavior to increase wellbeing and to decrease chronic disease, the implications for the study and application of EF on health behavior are widespread. Gaining knowledge of behavior from the cognitive sciences provides a powerful knowledge base that is being harnessed by other fields such as education, economics, and political science; this knowledge is being also employed by corporate marketers to encourage some behaviors that public health would like to discourage.

The neurocognitive sciences have grown exponentially since traditional health behavior models were developed and can offer powerful insights into the cognitive processes that drive behavior. The inclusion of EF into traditional models acknowledges the importance of self-regulation in health behavior, and dual process theory highlights the reason that it is needed – specifically, the strong pull of automatic processes and the environmental cues that can trigger them. These sciences and theories should be included

in public health behavior courses to expose future health behavior scientists with models that may better explain health behavior.

This expansion of thinking regarding health behavior not only offers a more comprehensive view of health behavior than traditional models but also points to powerful processes that can be harnessed to inform health behavior interventions. First, this speaks to underscoring the power of automatic behaviors. Automatic behaviors are effortless and immediate, and if they can be used to make healthy behavior automatic, they can be an influential force in public health.

Secondly, while EF is an individual-level characteristic, it has strong application to behavioral public health and potential for making population-level shifts in behavior and therefore health outcomes. As Hall et al. (2008) mention, consideration of an individual-level factor could, ironically, shift health behavior models away from motivation as a key driver of health behavior change and provide a strong rationale for environmental interventions. This is largely the underpinning for nudge interventions, and could be a promising area for promoting healthy behavior and discouraging unhealthy behavior.

Findings about EF and health behavior are especially salient for older populations, as EF, along with cognitive function in general, is known to decline with age (Brennan, Welsh, & Fisher, 1997; Royall, Palmer, Chiodo, & Polk, 2004). The bi-directional association between EF and health behavior could be something to harness to help encourage healthy aging – so that health behavior interventions could also be used to delay cognitive decline and vice versa.

Areas for Future Research

The published literature generally points to an association between EF and health behavior, but there is substantial research to be conducted to better understand this relationship and to better inform public health interventions and policy.

First, attention is needed regarding the theoretical models that underlie the study of EF/health behavior relationship to move the field beyond a deficit model and instead to investigate cognitive patterns that better explain health behavior. This would likely involve a consideration of each health behavior separately – including a careful consideration of which EF component(s) are implicated – to better understand the cognitive processes involved in each health behavior.

This also includes a consideration of applying a dual process model to various types of health behavior, including a consideration for whether dual process theories predict health-promoting behaviors as well as risky health behaviors, as it may be that the Reflective Impulsive Model is appropriate only for behaviors associated with an aspect of impulsivity. Additionally, specific dual process theories may need to be developed for different types of health behaviors. Dual process theories are used to explain behaviors ranging from economic decisions to alcohol consumption. Along with these different theories come different aspects of the “fast” processes that likely vary depending on the behavior of interest. Some work will be needed to determine the specific “fast” processes that lead to various types of health behavior. An emphasis on this aspect of health behavior is especially important, as Hofmann et al. (2009) point out, because much research has been devoted to self-regulation and comparatively little to impulses and associative processes. It will be important to bring balance to this trend to create effective interventions.

Along with the further development of models should come a refinement in the methods for studying EF and health behavior. This would include standardization of EF measures as well as a framework for considering the role of time in the measurement of EF and health behavior to gain understanding about how EF affects behavior from very short time frames (i.e., state EF) to then be added or multiplied over the course of a lifetime (i.e., trait EF). Longitudinal studies may be helpful in monitoring these relationships.

A more difficult, but ultimately helpful direction for future research would also be in studying the ecological validity of EF measures on “real world” health behavior. For example, how does EF impact decisions regarding physical activity and what observable differences are detected in real-life behavior in those of differing executive abilities? The ecological validity of EF is a recurring criticism of EF measures, but in the field of public health, it is critical to understand how low or high (or the changing state) EF resources translate into health behavior. This could ultimately inform interventions, prevention, and behavior change efforts.

Finally, this dissertation included research of the relationship between EF and health behavior in a population of older adults in a setting with considerable psychosocial and environmental factors that have reported associations with poor executive functioning, as well as poorer health behavior and poorer health. Small associations between EF and health behavior were reported here, but this neurocognitive consideration of health behavior could provide a nuanced contribution to our multi-level understanding about the social determinants of health. Future research could investigate the mechanisms

by which environmental factors literally “get under the skin” and affect cognitive function, health behavior, and ultimately, health outcomes.

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CURRICULUM VITAE

Sarah Godby Vail
Department of Health, Behavior and Society
Johns Hopkins Bloomberg School of Public Health
624 N. Broadway
Baltimore, MD 21205

Born November 10, 1973 in Columbus, Ohio

Education

Ph.D. candidate

Department of Health, Behavior and Society
Johns Hopkins Bloomberg School of Public Health
Baltimore, Maryland

Degree expected 2015

Master of Arts in Public Communication

American University
Washington, DC

August 2003

Bachelor of Science Journalism

Summa cum laude, Honors Tutorial College
Ohio University
Athens, Ohio
Specialization: French, Interpersonal Communication

June 1995

Research and Professional Experience

Survey Research Manager
Deloitte Consulting
Arlington, VA

September 2009-
May 2015

Federal Health Researcher
BearingPoint Consulting
McLean, VA

July 2005-July 2009

Research Coordinator, School-Based Mindfulness Program
Johns Hopkins Bloomberg School of Public Health
Baltimore, MD

January –
August 2008

Research Assistant, School of Public Communication
American University
Washington, DC

September 2002 –
August 2003

Teaching Experience

Graduate Co-leader, Mixed Methods Seminar Johns Hopkins Bloomberg School of Public Health Baltimore, MD	Spring 2010
Graduate Teaching Assistant, Social and Behavioral Aspects of Health Johns Hopkins Bloomberg School of Public Health Baltimore, MD	Summer 2008, Summer 2009
Graduate Teaching Assistant, Persuasive Communication Johns Hopkins Bloomberg School of Public Health Baltimore, MD	Winter 2009
Graduate Teaching Assistant, Doctoral Seminar Johns Hopkins Bloomberg School of Public Health Baltimore, MD	Fall 2008, Spring 2009
Graduate Teaching Assistant, Media and Communication School of Public Communication, American University Washington, DC	Spring 2003

Conference Presentations

Marshall, K., Jeffery, D., Klette, K., **Godby, S.**, Koeppl, P., Dobosz, B., & Rao, M. 2012. Prescription drug use and misuse among active duty military service members. Paper presented at the 140th Annual Meeting of the American Public Health Association. October, San Francisco.

Marshall, K., **Godby, S.**, & Koeppl, P. 2011. Flu vaccination prevalence in military health service beneficiaries newly recommended for vaccination. Paper presented at the 139th Annual Meeting of the American Public Health Association. November, Washington, DC.

Godby, S., Klassen, A., Carlson, M, Pollak, J, and Schwartz, B.S. 2012. Environment, self-regulation, and health behavior in older adults. Paper presented at the 139th Annual Meeting of the American Public Health Association. November, Washington, DC.

Godby, S., Pearson, J., & Klassen, A., 2009. Mixed methods in public health: A unifying tool in a multi-disciplinary field. Paper presented at the International Mixed Methods Conference. July, Harrogate, England.

Invited Presentations and Lectures

Mixed Methods in Public Health. Panelist, Mixed Methods Seminar,
Johns Hopkins Bloomberg School of Public Health, Winter 2012

Mixed methods in public health: A unifying tool in a multi-disciplinary field. Guest
lecture, Mixed Methods, Johns Hopkins Bloomberg School of Public Health, Spring 2010

Health Behavior Models, Guest Lecture, Social and Behavioral Determinants of Health,
Johns Hopkins Bloomberg School of Public Health, Summer 2010

Publications

Schwartz B.S., Stewart W.F., **Godby, S.**, Pollak, J., Dewalle, J., Larson, S., Mercer,
D.G., 2011. Body mass index and the built and social environments in children and
adolescents using electronic health records. American Journal of Preventive Medicine,
2011 Oct;41(4):e17-28. doi: 10.1016/j.amepre.2011.06.038.

Other Professional Activities

Student representative, Curriculum Committee 2008-2010
Department of Health, Behavior, and Society
Johns Hopkins Bloomberg School of Public Health
Baltimore, MD

Student co-organizer, planning committee Summer 2010
Session chair
Sixth Annual International Mixed Methods Conference

Honors and Awards

Departmental Scholarship for Doctoral Studies, 2007-2013
Departmental Research Support, 2009

Professional Memberships

American Public Health Association